U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

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COMPARATIVE ECONOMIC ANALYSIS OF THE LARC-5, THE LARC-15, AND THE BARC AND A GROUP OF TRANSPORT VEHICLES (CONCEPTUAL) UTILIZING THE PRINCIPLES OF HYDROPLANE, HYDROFOIL, AND GROUND EFFECT IN SHIP-TO-SHORE CARGO MOVEMENT

Task 9R38-11-009-26
Generalized Transportation Analogue Research

January 1962

DEPARTMENT OF THE ARMY

TRANSPORTATION CORPS

TASK 9R38-11-009-26

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FOREWORD

This report, one of a series of economic studies planned, was prepared in response to a general and growing need for economic information with respect to military transportation. The underlying research was conducted by Lt. Colonel James F. Wright, Jr., and Franklin J. McDermott in the Mathematical Sciences Division of the U. S. Army Transportation Research Command. The research was authorized and administered under Task 9R38-11-009-26.

The report is not intended to be the final word on the particular economic aspect of military transportation investigated. At this juncture, the intent is rather to provide a point of departure for more detailed and wider economic analyses and to afford a basis for inviting suggestions and comments from interested parties and agencies at large. Notwithstanding, the report serves in a gross way to reveal significant economic findings and conclusions.

1 September 1961

GEORGE D. SANDS
Director of Research (Acting)

PREFACE

In determining what investments to make in transportation resources—facilities, equipment, supplies, personnel—the military transportation executive and planner is vitally concerned with the fulfillment of the required movement capability. First and last, any investment in transportation must be judged and evaluated from the standpoint of providing the needed movement capability. Without the requisite lift capability, all other factors that might be introduced for assessment purposes have little or no meaning. Movement capability, where and when needed by the military commander, remains the final solution and criterion for any military transportation investment program.

Notwithstanding, with the continuing increases in defense expenditures, which now exceed $40 billion annually and absorb about 10 percent of the gross national product, the military transportation executive and planner has become acutely aware of, and very much concerned with, fundamental questions of economics in making investment decisions. What transportation resources, or development thereof, should be invested in? What quantity, and quality, of resource should be invested in? What will it cost to maintain and operate the transportation resources? What are the related costs measured in terms of educational and training requirements? Logistical requirements? What alternative investment choices exist? What is the optimum investment program?

The central economic problem and requirement, around which these questions revolve, is to identify all the pertinent costs so as to provide an optimum basis for choosing among alternative transportation investments, taking into account the economic impact or effect of each investment on the producing and consuming areas of the military and civilian economies. Each choice will involve a host of costs relating to development, first cost, depreciation, attrition, labor, fuel, maintenance, and other cost factors. Each will exert its particular force on the military economy and directly or indirectly impose its demand on the civilian economy, with corresponding decreases or increases in the efficient allocation of the national resources.

If economic factors are disregarded, or not adequately considered, in a military transportation investment program, the impact on the military and civilian economies can be as harmful or disastrous as defeat on a battlefield, and may be indeed the direct cause of such defeat. If the supply of capital, plant, goods, and labor were unlimited and served

equally well all national purposes, there would be no problem. But such is not the case. What is suggested, or should be recognized, is that the economic sciences, along with the engineering and technological sciences, form an indispensable basis of analysis for investment decisions relating to the procurement of transportation resources or to the development of these.

The present report is a comparative economic analysis of the LARC-5, the LARC-15, and the BARC—existing amphibians which embody the displacement hull principle—and a group of conceptual amphibians utilizing the principles of hydroplane, hydrofoil, and ground effect. The objective of the analysis is to determine the economic characteristics of the real and conceptual vehicles in question, with particular reference to capital costs, ton-mile costs, and other economic traits as a function of vehicular speeds and varying stage lengths. A second and related objective is to identify the significant cost factors and relationships that obtain, and to develop methodology for handling the type of research concerned here. At the outset, technical and operational analyses are made, as necessary to the purpose of economic analysis.

Since there is little direct technical, operational, and cost experience to fall back on, particularly in the case of the conceptual vehicles, the values assigned to some of the factors in the analyses were constructed, or arrived at, on the basis of the "best opinion" obtainable and comparable experience. The results of the analysis are accordingly indicative rather than conclusive. Nevertheless they should prove useful to the military transportation executive and planner in developing transportation investment programs and in revealing—since the report was also designed with this intention in mind--the value of economic research. Finally, any views expressed in this report are those of the authors, and do not necessarily reflect those of the Army Chief of Transportation.

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PART ONE. INTRODUCTION

The distribution of the world land masses and the related political ideologies and military capabilities emphasize for the West the vital importance of being able to move military personnel, equipment, and supplies over long lines of communication spanning large bodies of water and land with diverse environmental conditions. It implies, in the face of the present and foreseeable array of weapon systems and the associated unpredictableness and expansionist policies of certain nations, that our military forces must possess the necessary movement capability to move to, and in, any part of the world when called upon to do so. It implies, in the second instance, that our forces must possess the requisite degrees of transportation flexibility, responsiveness, and independence to exist, and to survive, in a nuclear climate. It implies, in the third instance, that the economic resources must be effectively allocated and that the transportation production and productivity must be maximized. The provision of movement capability, per se, and under the circumstances, presents formidable military transportation problems, in which the transport vehicle commands central attention.

Under the circumstances, the air vehicle would seem to present the ideal means of transporting military personnel and impedimenta overseas, from ship to shore, and on land. Operating in a single medium, the air, it is capable of moving swiftly over varying stages or distances without regard to the underlying geography with an accessibility factor at unity with the earth's surface. Cogent factors aggravate against the use of the air vehicle in every situation, however. It requires a place to land and to take off, though this may be nothing more than a small open deck area in the case of VTOL aircraft or helicopters and a grassy meadow in a forward sector for STOL aircraft. In spite of signal advances in communication and navigation systems, it continues to be acutely sensitive to weather. Moving in a highly exposed medium, it is subject to early detection and interdictory action. It is a large consumer and user of resources—human, machine,

capital.[1] It must maintain itself in the medium, in addition to moving in the medium, which makes for sizeable fuel and power requirements. Finally, it cannot at this time handle alone the tonnage, nor all the kinds of cargo, programmed or called for by a limited or a full-scale war.[2] For the time being, the role of the air vehicle—in intercontinental movement, at any rate—remains supplementary and in constancy with the requirement for a balanced, variegated transportation system.

The water vehicle continues, accordingly, to occupy a position of first importance in the movement of military personnel, equipment, and supplies between the world land masses. Coupled with the realization that the use of harbors and ports may be denied in times of war and that wide dispersion of vessels is mandatory, there is a concomitant need for the capability of moving military personnel and cargo from ships deployed over a large area to the beach and beyond. At the present time, this shuttle or transfer requirement is met by landing ships (vehicles which are capable of beaching) and wheeled amphibians (vehicles which are capable of beaching and moving upon the land), aided to a growing extent by helicopters. Both types of surface vehicles have demonstrated their vitalness and usefulness in past wars and in contemporary peacetime defense activities; for example, the utilization of the BARC, a large wheeled amphibian of recent design with a 60-ton payload (normal), for supply missions in support of Air Force

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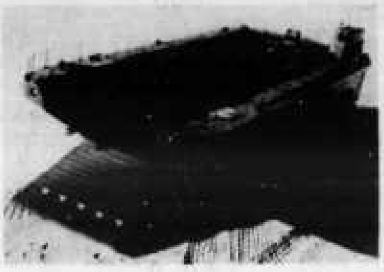
[1] On the other hand, a comparative economic study in which alternative transportation systems costs are analyzed might very well show that air movement for a given lift requirement or situation is less costly than surface movement, considering developmental costs, original and fixed costs, logistical support costs, and other pertinent costs, of a direct and an indirect nature.

[2] The role of the air vehicle is far from static, however. Increased payload capability, e.g., obtained simply by eliminating nonessential items from aircraft (see: Herbert A. Nelson, Major, USMC, "Bigger Payloads for the HUS", Marine Corps Gazette, Vol. 45, No. 4, April 1961, pp. 52-56); reduced cargo size and weight, e.g., obtained from the utilization of Californium, a fissionable element which conceivably could be fashioned into bullets, each with a 10-ton TNT explosive equivalent, for use with "atomic rifles or pistols" (see: Herman Kahn, On Thermonuclear War, Princeton University Press, Princeton, N. J., 1960, 651 pp.); and changes and advantages obtaining elsewhere can be expected to increase the employment of the air vehicle in the years ahead.

installations in the Arctic.[3] The BARC, the LARC-5 (5-ton payload), which is scheduled for quantity production, and the LARC-15 (15-ton payload), currently under development, constitute a new family of wheeled amphibians (Exhibit 1) designed to provide the Army with improved surface movement capability from ship to shore and away from the beach. However, they are limited, as are other currently available amphibians, to a maximum water speed of about 10 knots (see Exhibit 2).



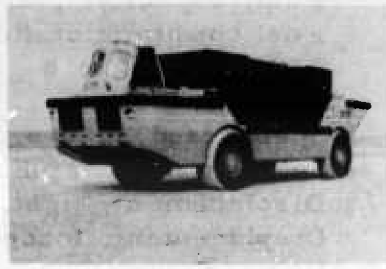


Exhibit 1. The BARC, the LARC-5, and the LARC-15.

An increase in speed can be obtained from an increase in the specific power, that is, the ratio of installed horsepower to gross weight, which is made more feasible with the advent of gas-turbine engines. An increase in speed can also be achieved through weight reduction and by streamlining. As reported,[4] the replacement of the reciprocating gasoline engine (805 horsepower) with a gas-turbine engine (900 horsepower) boosted the speed of the Marine Corps amphibious, tracked, landing ship LVTP-5 (a personnel and cargo carrier) by 30 percent and the payload by 5,000 pounds. In recent studies and experiments with a one-tenth scale model and a full-size modified World War II DUKW, a 25-percent reduction in hull drag at 10 miles per hour was realized with wheel retraction and a clean, or faired, hull.[5] Such achievements and improvements are to be noted.

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[3] After Action Report, Subport Frobisher, 1955 (reports initial operation of the BARC in the Arctic), Hq, 7278 GU, U.S. Army Transportation Terminal Command (Northeast Air Command), APO 862, New York, New York, 1955, 10 pp., and annexes A through H; After Action Report, Subport Frobisher, 1956, Hq, 7278 GU, U.S. Army Transportation Terminal Command (Northeast Air Command), APO 862, New York, New York, 1956, 30 pp., and annexes A through K.

[4] "Gas Turbine Speeds Landing Vehicle", Automotive Industries, Vol. 123, No. 4, 15 August 1960, p. 51.

[5] Louis S. Votre, The New Trend in Fast Assault Vehicles, Avco Corp., Stratford, Connecticut, 12 October 1960, p. 1.

Exhibit 2. Basic Characteristics of LARC-5, LARC-15, and BARC.

Details	LARC-5	LARC-15	BARC
Length, overall, ft.	35.0	45.0	62.5
Width, overall, ft.	9.0	12.5	26.6
Height, overall, ft.	9.3	13.3	19.4
Hull, material	Alum	Alum	Steel
Engine, type, number	Gasoline (1)	Gasoline (2)	Diesel (4)
Engine, hp.	270	540	800
Fuel, capacity, gal.	135	426	600
Fuel consumption (full throttle), g.p.h.	20	40	38
Crew, number	2	3	8
Speed, land, m.p.h., max.	23.7	23.5	14.0
Speed, water, m.p.h., max.	9.7	9.5	7.4
Displacement, light, tons	9.0	16.5	97.9
Displacement, loaded, tons	14.6	34.0	160.4
Payload, tons	5.0	15.0	60.0
Payload/displacement, percent	34.2	44.1	37.4

At the same time, it must be recognized that no significant increase in speed—of the order of 4 × 10 or 8 × 10—can be obtained from vehicles utilizing displacement hulls without sharp increases in power needs. See Exhibit 3. Increasing the speed of, say, a 55-foot boat with a displacement hull from 10 miles per hour to 40 miles per hour would increase the power need from 100 shaft horsepower to 1,000 shaft horsepower approximately, or tenfold.[6] For a wheeled amphibian of, say, 45 feet, the installed power requirement for a moderate advance in speed from 10 to 12 knots jumps from 17 horsepower/ton to 34 horsepower/ton, or double.[7] The power requirement for land movement is seldom more than 15 horsepower/ton.[8]

[6] Allan B. Murray, "The Hydrodynamics of Planing Hulls", Transactions, 1950, The Society of Naval Architects and Marine Engineers, Vol. 58, New York, New York, 1951, p. 658.

[7] Kenneth A. Austin and Louis S. Votre, Turbine Driven Amphibians—The New Trend in Fast Assault Craft, a paper presented before the Chicago Section of the Society of Automotive Engineers, 11 October 1960, p. 2.

[8] Ibid., p. 2.

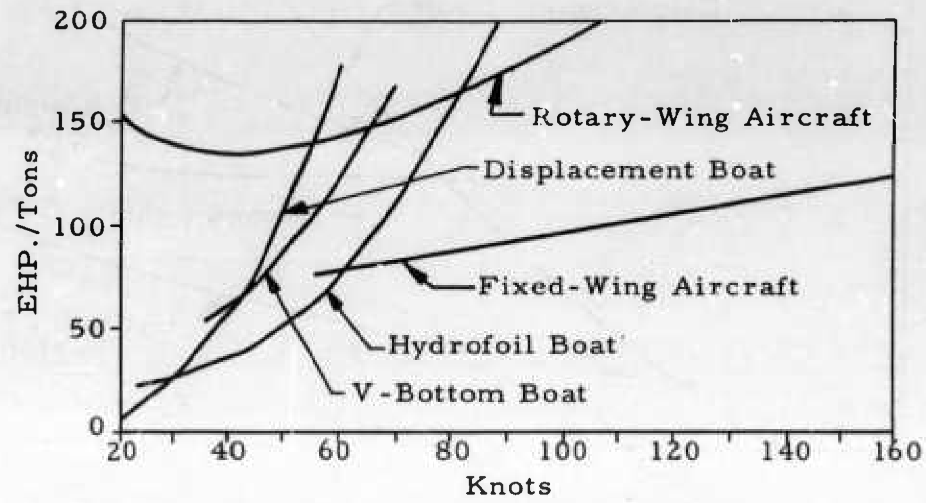

Exhibit 3. Power Coefficient of Various Types of Vehicles. (Source: Baron H. von Schertel, Design and Operating Problems of Commercial Hydrofoil Boats, a paper given at the Third Symposium on Naval Hydrodynamics (a joint meeting of Office of Naval Research and Netherlands Ship Model Basin), Scheveningen (The Hague), Netherlands, 19-22 September 1960.)

For small amphibians, as presently designed with water-displacing hulls, the practical speed limit is about 10 knots. Beyond this upper limit of speed, speed becomes very costly. Payload and range are bound to suffer, among other economic and operational disadvantages. In the technical area, the problem soon arises as to where to put the power plant of the size imposed and how to convert the power to thrust. To some extent, this problem is resolved by the utilization of gas-turbine engines.

Fundamentally, the difficulty arises from the resistance of water-displacement hulls to motion (drag). See Exhibit 4. The drag is due in part to the skin friction at the boundary of the hull and in part to the form resistance of the hull itself. The former can be reduced by decreasing the wetted surface and making it smooth; the latter, by reducing the immersed volume and by streamlining. Resistance also arises from surface waves that a vessel creates in moving in the

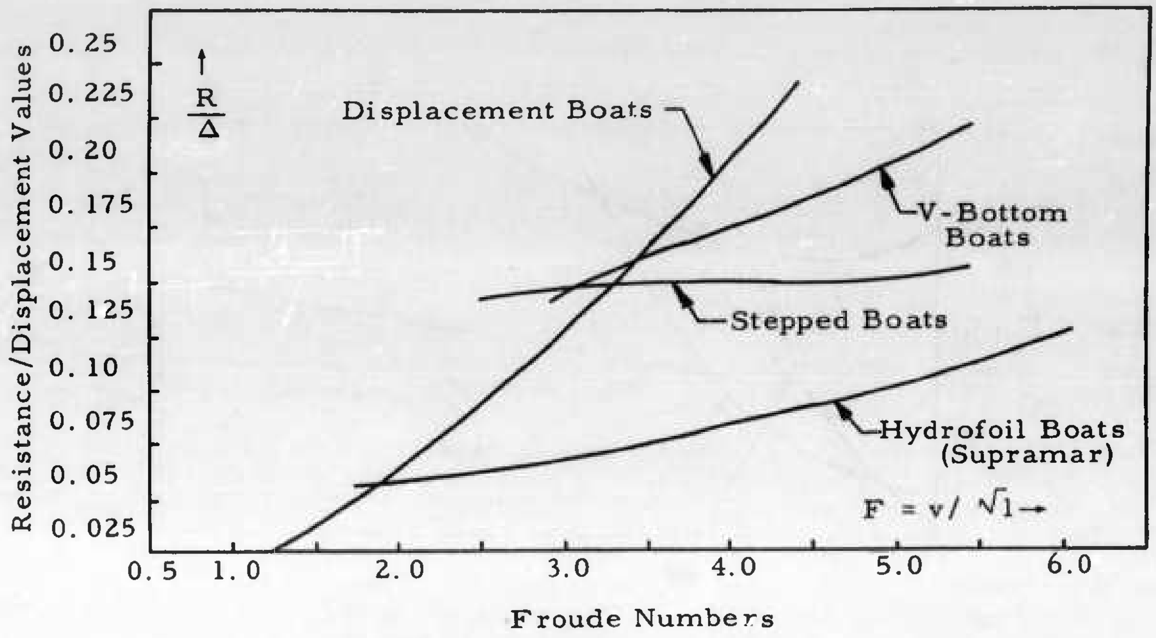

Exhibit 4. Diagram of Drag/Lift Ratio Curves.

boundary, or interface, between two media of very different densities. Beyond a certain speed, wave resistance becomes a major source of drag, increasing steeply with speed. Wind is still another source of interference, acting directly in the form of dynamic pressure and indirectly in the form of waves.

As a consequence of the inherent low-speed capability of the displacement-hull-type water vehicle, there is currently substantial interest and research experimentation, and considerable development, relating to vehicles that employ hydroplane, hydrofoil, and ground effect principles. Such employment, involving hydrodynamic and aerodynamic laws, obviates completely the problem of water resistance in the case of ground effect vehicles and reduces water resistance to low levels in the cases of hydroplane and hydrofoil vehicles, to produce vehicles inherently capable of moving easily at speeds of 40 miles per hour and better. The technical feasibility of applying hydroplane, hydrofoil, and ground effect principles to the development of high-speed amphibians, incorporating wheel retraction systems in the hydroplane and hydrofoil amphibian designs, is indicated at this time. However, the question remains as to whether high-speed amphibians embodying the principles in question are economically feasible.

PART TWO. TECHNICAL AND OPERATIONAL ANALYSIS

In this section, three objectives are established and accomplished as part of, and as necessary to, economic analysis. The objectives are: (1) to examine the state of the art as it relates to the principles of hydroplane, hydrofoil, and ground effect, and their application, with emphasis on actual transportation experience so far as possible; (2) to identify the technical and operational requirements, limitations, and potentialities assignable to vehicles embodying the principles in question in order to provide a realistic and firm basis of comprehension; and (3) to develop conceptually a group of hydroplane, hydrofoil, and GEM amphibians for economic test purposes, based on the information produced in (1) and (2) and supporting estimates and calculations.

STATE OF THE ART

The hydroplane principle has been known for the better part of a century. As applied, it describes a vehicle, or boat, which is capable of skimming on water rather than moving through it. See Exhibit 5.

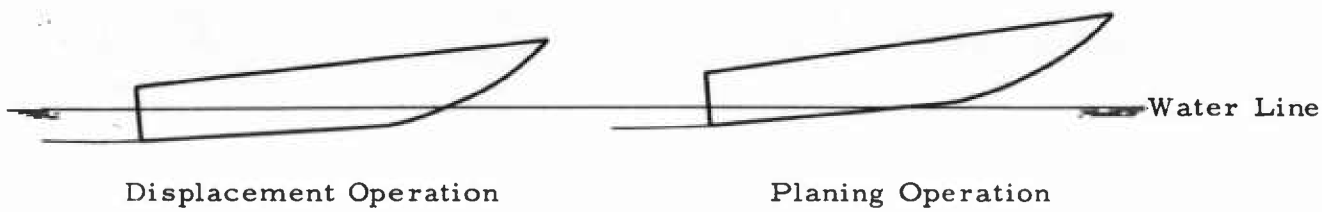

Exhibit 5. Schematic View of Hydroplaning Action.

The chief advantage of the hydroplane boat is speed coupled with certain derived economies, namely, those arising from the much smaller amount of power that is required to lift a planing hull out of the water toward the surface (thereby reducing water drag significantly) than is required to accomplish the same job utilizing a conventional water-displacing hull. This advantage is shown diagrammatically in Exhibit 10, on page 21, which shows curves of shaft horsepower against speed in knots for two 22,000-pound boats, one a round-bottom design of 55-foot length and one a planing-hull design of 44-foot length. The tabulation on

the chart gives the shaft horsepower for each design for several speeds up to 40 knots.

The hydroplane principle has been applied for a number of years to the development of high-speed (above 15 knots), small boats (below 130-foot length) for private, commercial, military, and civil government uses. By about 1913, the hydroplane influence was strongly evidenced in hull offerings at the annual National Motor Boat Show in New York. One planing-hull boat exhibited at the 1913 boat show was a 16-foot boat equipped with a three-cylinder, two-cycle motor of only 18 to 25 horsepower, which "flew" at 28 miles per hour. In the same year, the Hickman Sea-Sled was demonstrated for the first time. This planing boat had a vee'd concave section in the forward half of its hull, and only partially submerged propellers. The engine was placed in the stern instead of forward as usual. The power plant was a 25-horsepower gasoline engine weighing 400 pounds, which drove the 1,600-pound boat (2,000 pounds with engine) over the water at 26 miles per hour at a horsepower/pound ratio of 1 to 80. During World War I, the British Navy operated a number of fast patrol boats embracing the planing principle in their hull design.

The present-day array of hydroplane boats comprises runabouts, racing boats, cabin cruisers, fishing boats, air/sea rescue launches, antisubmarine warfare vessels (ASW), target boats, and experimental items. They include V-bottom boats with steps, single- and multiple-step boats, inverted V-bottom or sea-sled boats, and three-point hydroplanes. They range in length from 15-foot pleasure boats commonly seen on lakes and rivers and in coastal waters during the summer months to 100-foot plus military vessels, such as the German "E-boats" of World War II and the HMS BRAVE SWORDSMAN, a hydroplane boat (experimental) delivered to the Royal Navy in 1960. Gasoline and diesel engines, and, to a growing extent, gas-turbine engines, are widely utilized, with shaft and water propeller arrangements similar to those commonly found on displacement-hull boats. They employ various materials in the hull construction and in the structural members. To a growing extent, lightweight materials, aluminum and fiberglass, are being utilized. A representative group of operational and experimental hydroplane boats is listed in Exhibit 6 with pertinent details. The list includes a Marine Corps hydroplane amphibian (experimental), presently under construction, and a second hydroplane amphibian (experimental), proposed for construction.

Exhibit 6. Hydroplane Vehicles - Technical, Operational, and Other Details

Item	Vehicle	Builder/Designer	Application	Hydroplane Type	Year Launched	Length (ft.)
1	PT 809 (Navy)	Electric Boat Co.	Torpedo boat (O)	V-Bottom	1950	85.0
2	HTS	Boeing Co.	Hydrodynamic test system	3-Point	1961-62	38.0
3	Inboard Skiff	Chris Craft	Pleasure (O)	-	-	27.0
4	LCW (USMC)	Borg-Warner Corp.	Amphibian (E)	V-Bottom	1962-63	-
5	(Prelim. design)	Borg-Warner Corp.	Amphibian (E)	V-Bottom	-	56.0
6	HMS BRAVE SWORDSMAN	Vosper, Ltd.	Patrol boat (E)	V-Bottom	1960	89.0
7	SKYLARC (Prop. design)	Borg-Warner Corp.	Amphibian (E)	Inverted V-Bottom	-	40.0
8	MERCURY	Vosper, Ltd.	Yacht (O)	V-Bottom	1961	102.0

E = Experimental, Ev = Evaluational, O = Operational

Exhibit 6, contd.

Item	Hull Material	Propulsion Power (no.)	Propulsion Output (hp.)	Propulsion Transmission	Displ. (tons)	Payload (tons)	Payload (% displ.)	Speed (k.)	Range (n. mi.)
1	Alum	Gasoline (4)	10,000	Conventional Shaft Drive	58.0	-	-	420	-
2	Alum	Gas Turbine (1)	1,400 at 100 knots	Jet Propulsion	6.5	-	-	100+	2-3
3	Wood	Gasoline (1)	185	Conventional Shaft Drive	2.3	-	-	27.0	280
4	Alum	Gas Turbine (1)	1,500	Retractable V-Drive	19.0	5.0	26.0	30.0	-
5	Alum	Gas Turbine (2)	2,000	Outboard, Retractable Drive	45.0	15.0	33.3	25.0	-
6	Alum	Gas Turbine (3)	10,500	Conventional Shaft Drive	95-100	-	-	50.0+	400 mi. at 46 knots
7	Alum	Gas Turbine (2)	1,880	Outboard, Retractable Drive	20.0	5.0	25.0	25.0	-
8	Alum	Gas Turbine (3)	10,500	Conventional Shaft Drive	-	-	-	54.0	400 mi. at 46 knots

Essentially described, the water vehicle employing the hydrofoil principle consists of a displacement (or planing[9]) hull equipped with fixed or retractable foils. As a result of the natural forces acting upon these foils, or underwater wings, the hull is gradually lifted as the speed of the vehicle increases, in a manner similar to the effect of the airstream on the wings of an aircraft. When a certain speed is reached and the lift generated on the foils exceeds the weight of the vehicle, "take-off" occurs, and the vehicle emerges clear of the water and moves forward in a foilborne position. Resistance to the hull is eliminated, drag is reduced to that for the foils and supporting struts alone, and the action of the waves is to a large extent neutralized, unless the waves exceed a certain size in relation to the length of the vessel. The end result is low power and high speed—up to the limit of subcavitation speeds (below 40 to 60 knots).[10] At supercavitation speeds (above 40 to 60 knots), power needs rise precipitously.

The hydrofoil principle was first applied about 75 years ago, in France, with the demonstration on the Seine River of a boat with a foil-like arrangement. The first really successful demonstration of the principle, however,

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[9]A planing vehicle with hydrofoils represents an alternative approach to high speed. In recent tank tests of a planing boat model, it was found that water resistance could be reduced as much as 27-1/2 percent when foils are added. As further reported, the planing hull-hydrofoil arrangement, in addition to being practical basically, could be adapted to existing hulls having conventional shafting systems, would improve the trim angle of the vehicle, and would provide sufficient stability to obviate the need for a complicated and costly electronic or mechanical incidence control system. Source: Peter Sherman, Tests of a Planing Boat Model with Partial Hydrofoil Support, Report 1254, Department of the Navy, David Taylor Model Basin, Washington, D. C., August 1958.

[10]By definition, lift is produced by the formation of a pressure differential: compression on the bottom of the foil (superpressure) and rarefaction on the top of the foil (subpressure). Cavitation occurs when, with the movement of a foil through a liquid beyond a certain speed, the pressure at the top drops to the vapor pressure of the liquid and leads to the formation of bubbles. These bubbles wander in the higher pressure zone, that is, in the area of the rear wing edge, where they collapse and damage is caused to the water system, reducing thereby the efficiency of the foil. The alternative is to accept speeds below 40 to 60 knots (subcavitation) or to design for speeds above 40 to 60 knots (supercavitation). Considerable research and experimental work remain to make supercavitation fully practical.

took place in Italy around the turn of the century, with fully emerging hydrofoil boats, which were said to have attained speeds of up to 45 miles per hour. In 1919, a Canadian hydrofoil boat, the HD 4, displacing 5 tons and powered by two 350-horsepower aircraft engines driving air propellers, reached a maximum speed of 60 knots. From the early thirties to the end of World War II, the principle was intensively applied in Germany. During this period, nine different types of hydrofoil boats with displacement weights ranging from 4 to 80 tons and up to 50 knots in speed were designed and built for the German Navy and Army for experimental and operational (evaluation) purposes. One of these, the VS 8, displacing 80 tons and measuring 105 feet in length, could make 40 knots. It was designed for high-speed tank-transport operations between Sicily and Africa. The German effort served instrumentally in putting the application of the hydrofoil principle on a practical basis.

In the period since the end of World War II, more particularly since the early 1950's, the hydrofoil principle has been applied on a widening scale. A sizeable number of hydrofoil vehicles have been constructed for experimental purposes serving private, military, and civil government objectives and for commercial and other regular service applications utilizing principally the German experience. They include significantly the Grumman XCH-4, the HALOBATES, the SEA LEGS, and the FLYING DUKW in the experimental category of hydrofoil vehicles and the Supramar boats—PT 10, PT 20, and PT 50—in the commercial and regular service operations category of hydrofoil vehicles. Other hydrofoil vehicles are currently under construction, such as the Navy PC(H), a 45-knot, 115-foot, 110-ton hydrofoil boat for ASW operations (evaluation), and the Maritime Administration HS DENISON, a 60-knot, 105-foot, 80-ton, hydrofoil boat for commercial operations (evaluation). Still others are projected or planned for the future. Exhibit 7 contains a tabulation of most of the hydrofoil vessels built since 1940, either for experimental or practical applications, with pertinent information. Included is one Soviet hydrofoil boat.[11]

[11] As reported, hydrofoil boats are used extensively in the Soviet Union on their rivers and lakes. The RAKETA, an 88-foot, 23-ton hydrofoil boat, is capable of carrying 66 passengers at a speed of 40 knots. Approximately 60 of these transports are in use. The METEOR, a second Soviet hydrofoil boat, displaces 53 tons, has a speed of 40 knots, and carries 150 passengers. It has been in regular service for some months on the Volga between Gorki and Ulyanovsk. The SPUTNIK, largest of the series, is a 107-ton craft, capable of carrying 300 passengers and attaining a speed of 40 knots. Source: J. K. Roper and I. Palmer, An Introduction to Hydrofoil Seacraft, Grumman Aircraft Engineering Corporation, Bethpage, L.I., New York, undated, p. 2; and K. Büller, "Hydrofoil Craft of Today and Tomorrow", Interavia, Vol. XVI, No. 4, April 1961, p. 482.

Exhibit 7. Hydrofoil Vehicles - Technical, Operational, and Other Details.

Item	Vehicle	Application	Designer &/or Builder	Foil System	Year Launched	Length (ft.)	Hull Material
1	TS 6 (Germany)	E, O (Ev)	Schertel	SP, NR	1941	39.3	Steel
2	VS 6 (Germany)	E, O (Ev)	Schertel	SP, NR	1941	50.0	Steel
3	VS 8 (Germany)	E, O (Ev)	Schertel	SP, NR	1943	105.0	Alum
4	TK (USSR)	E, O (Ev)	(German design)	SP, NR	1948	83.3	Alum
5	PT 10 (Switz.)	O (Pass.)	Supramar	SP, NR	1952	47.0	Wood
6	XCH 4	E	Grumman	SP	1953	53.0	Alum
7	XCH 6	E	Grumman	S	-	23.0	-
8	High Pockets	E	Baker	SP	1953	24.0	-
9	PT 3 (Switz.)	O (Police)	Supramar	SP, NR	1954	34.8	Alum
10	PT 20 (Switz.)	O (Pass.)	Supramar	SP, NR	1955	68.0	Alum
11	PT 21 (Switz.)	O (Pass.)	Supramar	SP, NR	1955	66.0	Alum
12	Halobates	E	Miami S. C.	S	1957	40.0	-
13	Sea Legs	E	Gibbs and Cox	S	1957	29.0	-
14	Bras D'Or (Can)	E	Saunders-Roe	SP	1957	59.0	-
15	Aquastroll (Fr.)	O (Pass.)	Intl. Aquavion	S	1957	47.1	-
16	PT 27 (Switz.)	O (Pass.)	Supramar	SP	1958	69.9	Alum
17	PT 50 (Switz.)	O (Pass.)	Supramar	SP	1959	88.6	Alum
18	Flying DUKW	E (Amphib.)	Avco (Lycoming)	S, NR	1959	32.0	Steel
19	HS Denison	O (Ev)-Pass.	Grumman	SP, R	1961	104.6	Alum
20	PC(H)	O (Ev)-ASW	Boeing	S, R	1962	115.0	Alum
21	HTS	E	Boeing	S	1962	38.0	Alum
22	PT 90 (Switz.)	O (Pass.)	Supramar	SP, NR	1962	117.5	Alum
23	PT -- (Switz.)	O (Pass.)	Supramar	SP, NR	-	-	-
24	AG (EH)	O (Ev) - ASW	Boeing	S	(proposed)	-	-
25	-	O (Ev) - O	Grumman	S	(proposed)	-	-

E = experimental, Ev = evaluation, O = operation.

SP = surface-piercing foils   S = completely submerged foils

R = retractable foils   NR = nonretractable foils

Exhibit 7, contd.

Item	Propulsion System: Power	Output (hp.)	Transmission	Displ. (tons)	Hp. Displ.	Speed (k.)	Range (n. mi.)	Payload (tons)	Payload (% displ.)
1	Gasoline	380	Bevel gear drive	6.2	61.3	40.0	-	1.4	22.2
2	Diesel	1,400	-	17.2	81.4	47.5	-	3.0	17.7
3	Diesel (2)	4,000	Str. shaft drive	80.0	50.0	43.0	-	26.0	32.5
4	Diesel (2)	5,000	-	-	-	47.0	-	-	-
5	Diesel	500	V-drive shaft	9.2	54.3	47.0	-	2.6	28.2
6	Gasoline (2)	1,260	Air propellers	8.0	157.5	75.0	-	-	-
7	Turbine	200	Bevel gear drive	1.0	200.0	60.0	-	-	-
8	-	125	-	2.8	44.6	36.0	-	-	-
9	-	150	V-drive shaft	-	-	31.0	-	-	-
10	Diesel	1,350	V-drive shaft	28.0	48.2	42.0	300	6.8	24.3
11	-	1,300	-	-	-	43.0	-	-	-
12	Turbine	825	Bevel gear drive	15.5	53.2	36.0	-	4.0	26.6
13	Gasoline	210	V-drive shaft	5.0	42.0	31.0	-	-	-
14	Gasoline (2)	3,000	Bevel gear drive	20.0	150.0	55.0	-	3.5	17.5
15	-	500	-	16.7	29.9	38.0	-	3.2	19.4
16	Diesel	1,350	-	-	-	40.0	-	-	-
17	Diesel (2)	2,700	Str. shaft drive	60.0	45.0	40.0	300	15.0	30.0
18	Turbine	860	Bevel gear drive	13.0	66.2	27.0+	-	-	-
19	Turbine	16,500*	Bevel gear drive	80.0	206.3	60.0	855	10.0	12.5
20	Turbine (2)	6,200**	Bevel gear drive	110.0	56.4	45.0+	-	-	-
21	-	-	-	5.0	-	100.0+	-	-	-
22	Turbine (2)	8,500	-	130.0	65.4	53.0	-	-	-
23	Turbine	35,000	-	250.0	140.0	70.0	-	-	-
24	-	-	-	300.0	-	-	-	-	-
25	-	-	-	500.0	-	60.0	-	100.0	20.0

*Plus turbine for hullborne operation.

**Plus diesel for hullborne operation.

The significance of the ONR experimental XCH 4, which was equipped with a fully submerged foil system, arises from its aircraft-like configuration, the high speeds obtained without cavitation (up to about 60 knots), and the very high speeds obtained otherwise (in excess of 80 knots cavitating). It was first tested in 1953. SEA LEGS, another Navy experimental hydrofoil vehicle, first tested in 1957, is significant because it employed an electronically stabilized, fully submerged foil system. The experimental HALOBATES, also tested in 1957 for the first time, successfully demonstrated the application of the hydrofoil principle to a landing craft (modified Navy LCVP). It employed a fully submerged, incidence-controlled, retractable foil system. In its turn, the Army FLYING DUKW demonstrated, in 1959, the successful application of the hydrofoil principle to wheeled amphibians, confirming theoretical studies and towing-tank model tests. Modified along the same lines as the Navy HALOBATES, which is also comparable in size and displacement, the FLYING DUKW consisted essentially of a standard World War II steel-hull DUKW equipped with solid-aluminum, nonretractable, fully submerged, front hydrofoils and struts; a 725-horsepower gas-turbine engine; a retractable, right-angle, over-stern, tractor propeller, with an attached, single, rear, submerged hydrofoil; and an automatic (electronic) stabilizer system. See Exhibit 8.

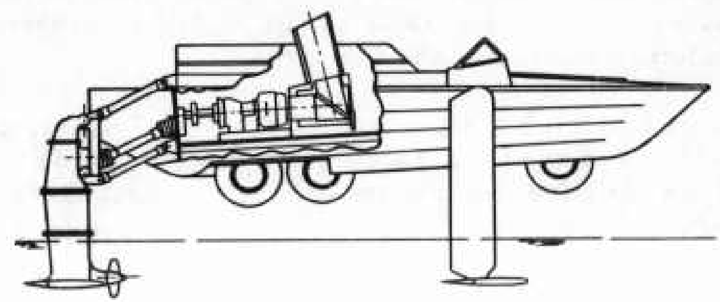

Exhibit 8. Section Drawing of the FLYING DUKW.

The PT 10, the PT 20, and the PT 50 are significant because they are employed in regular transport service in different parts of the world, affording collectively the only basis for evaluation of hydrofoil vehicles on an actual operational basis in the western world. The first of these has been in service since 1953. All are equipped with surface-piercing foil arrangements.

Foil arrangements, it may be noted here, are of two fundamental types: (1) arrangements in which the foils penetrate the water and (2) arrangements in which the foils are fully submerged. In the first system, the

foils are fixed in attitude with respect to the hull and derive lift from the submerged or wetted area of the foils, with the lift coefficient remaining substantially constant. When changes in the height of the boat over the water are experienced because of wave action, and concomitantly changes in the submerged area of the foils and corresponding lift-producing capability of the foils, the hydrofoil boat rises or sinks of its own accord until equilibrium is re-established. Surface-piercing hydrofoil systems are therefore automatically stable. In effect, the foils perform the dual function of sensing the required lift coefficient and providing it.

In the fully submerged hydrofoil system, the attitude of the foils is not fixed. The angle of attack on the foils is variable to compensate for wave heights and to meet other impositions. Such variation is not inherent in the submerged foil system (as it is in the surface-piercing foil system). Variation must be provided. This may be accomplished by manual, mechanical, or electronic means, which measure the distance between the hull and the water surface or foil-submergence and change the angle of incidence of the foils (or of the flaps at the trailing edge, if flaps are employed) to provide the required change in lift. It can be seen that hydrofoil theory and practice are very closely related to airfoil theory and practice. A second classification of foil arrangements relates to the longitudinal distribution of the foil area.

The surface vehicle utilizing the ground-effect principle is, strictly defined, an air vehicle that operates close to the ground or a water surface. It derives its lift from ground-effect forces, which may be augmented by aerodynamic forces and jet reaction forces. Aerodynamic lift is dependent upon the planform and contour of the ground-effect machine (GEM) and the forward velocity. Jet lift is obtained from the thrust force of air. The ground-effect lift is achieved from a cushion of superpressure (above atmospheric pressure) air beneath the vehicle and upon which it rides. The power expended by the GEM vehicle is used to generate and maintain the air cushion supporting the vehicle and to provide horizontal movement capability and vertical movement capability on a very limited basis. The special advantage arising from the application of the ground-effect principle is the greater lift and lower induced drag experienced in operating close to the ground than that experienced outside the zone of ground effect, with concomitant effects on power requirement and consumption, coupled with high speed and accessibility capabilities. The operating altitude of a GEM vehicle, a function of design and operating needs governed by practical and natural limits, may vary from a fraction of an inch to several feet.

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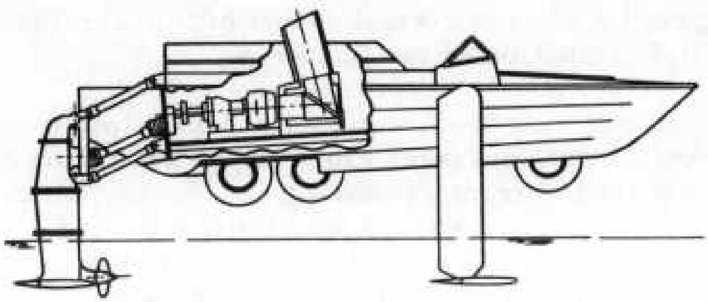

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The ground-effect principle is not new. In 1883, it was applied by Dr. G. de Laval in an experimental device that forced compressed air between a ship surface and the water in an attempt to provide "air lubrication" of the boundary layer between the ship's hull and the water. In 1904, it was applied in the aerodynamic theory established by Ludwig Prandlt, a German aerodynamicist. His studies revealed that when a wing was in close proximity to the ground at a fixed angle of attack, the effective angle of attack and the total lift were greater and the induced drag was lower than when the wing was out of ground effect. This indicated that there was an upwash effect on the wing and thus explained the effective angle of attack's being greater than the actual. The ground-effect phenomenon has been observed practically in aircraft operations for many years. The effect is particularly noticeable in, and applicable to, helicopter operations.

Beginning in the 1920's, the principle was applied in experimental vehicles operating completely in ground effect. Such application included the work of Dr. A. Kucher, who introduced the levapad concept in 1928, the efforts of D. K. Warner beginning in 1930, and the activities of T. Kaario of Finland, who built several GEM vehicles, starting in 1935, based on the ram-wing concept. During the past 5 or 6 years, the ground-effect principle has become the object of considerable theoretical and experimental work, including scaled and full-scale models. Exhibit 9 contains a tabulation of existing and contemplated experimental GEM vehicles with pertinent data.[12] Included are only GEM vehicles capable of carrying a payload of 200 pounds or more, including fuel and crew. To date, no practical application of the GEM principle has been made.

The majority of the GEM experimental vehicles listed, it will be noted, are based on the annular seal system, followed next by the plenum system. In the annular system, the air produced by the vehicle for the air cushion is delivered downward and inward via nozzles located around the edge of the base of the vehicle. In addition to supplying air to the air cushion, the peripheral air exhaust acts as a curtain to contain or seal

[12] As reported, a GEM vehicle is under development for river use by the Central Technical Design Bureau of the Russian Soviet Federated Socialist Republic's Ministry of the River Fleet. An experimental model will be built with a carrying capacity in excess of 4 tons and a maximum speed of 34 miles per hour. Lift will be provided by two aircraft engines. A third engine mounted in the rear will propel the craft with the assistance of an aircraft-type rudder. Source: "Soviets Are Developing Air-Cushion River Boat", Aviation Week, Vol. 74, No. 10, 6 March 1961, p. 57.

Exhibit 9. GEM Vehicles - Technical, Operational, and Other Details.

Company	Model No. Name	Type of Seal	Planform Length, Breadth, Height (ft.)	Empty Weight (lb.)	Installed BHP	Cush. Pressure (lb./ft.^{2})	Hovering Height (in.)	Maximum Speed (k.)	% Grade	Payload Incl. Fuel & Crew (lb.)	Special Features
Aerophysics (USMC)	GEM II	Annular	34.6 x 26.7 x 10.6	15,000	740	28.5	8	50 x	9	10,000	
American Mach. & Foundry	-	Annular	5 dia. 3 units joined	390	9	10	1	-	-	195	
Antifriction Hull	Hydrokeel	Plenum	24 x 8 x 5	3,500	185	-	-	33	-	1,000	
Avro	Avrocar	Annular	18 dia. x 5	3,426	3,000	21.5	36	225 x	-	2,224	Getol, focussed jet
Bell Aerosystems	2015	Plenum	18 x 8 x 4	1,500	65	23	2	-	1	500	
	2033	Annular	18 x 8 x 4	1,700	140	40	-	-	-	800	Sidewall skegs
Bell Helicopter	Air Scooter	Plenum	7.1 x 4.6 x 3.0	180	16	12.5	2	24	10	172	Controlled flow
Bertelsen Mfg	-	Annular	11.5 x 7.9 x 3.2	1,600	178	23.5	12	-	10	800	
	Aeromobile	Plenum	8.4 x 5.9 x 2.7	408	72	12	6	35	-	175	
Britten-Norman	Cushioncraft	Annular	19 dia. x 10	2,000	170	11.5	15	35 x	-	1,000	Shrouded ann. rotor of same dia. as jet
Curtiss-Wright	ACM 1-1	Plenum	16 x 11 x 6	1,050	75	10	1.5	20	4	450	
	ACM 2-1	Plenum	21 x 8 x 5	2,500	300	21	12	26	8	960	
	ACM 2-2	Annular	21 x 8 x 5	3,500	300	21.5	9	35	10	960	
	ACM 6-1	Annular	17 x 7 x 5	2,300	300	29.2	6	55 x	13	960	
Fletch-Aire	Glidemobile	Annular	14.2 x 5.5 x 3.3	287	72	8	4	37	4	184	
Folland Aircraft	Germ	Annular	15 x 8 x 4.5	1,300	95	16	-	42 x	-	300	Swivelling ducted fan
Ford Motor	Levacar	Levapad	7.8 x 4.5 x 4.0	450	16.5	5,040	.015	13	-	175	Three rails
Goodyear Aircraft	-	Plenum	8 x 5 x 5	750	35	25	1	-	-	250	Flexible airmat understructure. No forward prupulsion.
Gyrodyne Co. of America	55	Annular	9.24 x 6.0 x 5.37	535	65	32	6	8	-	260	Uses single annular ejector
Hovercraft	SRN-1	Annular	30 x 24 x 12	8,500	435	17	15	23	-	1,100	Concentric annular jets
	SRN-1 (mod.)				800 lb. thrust			43			Morbore engine added
	SRN-2	Annular	65 x 30 x	30,000	3,750	-	-	70 x	-	20,000	
Hughes Tool	STV	Waterwall	22.6 x 10.5 x 8.1	3,402	225	24	24	22	-	1,760	Side skegs
	DTV	Waterwall	15.7 x 9.1 x 7.7	1,630	225	17	-	-	-	320	All water curtain
McDonnell Air. Corp.	-	Annular	17.5 x 7.0 x	415	65	-	-	-	-	180	Getol, cir. fuselage
National Research Assoc.	GEM I	Annular	14.6 x 8.2 x 4.3	1,050	66	11	14	30	7	230	
	GEM III	Annular	24 x 12 x 7.1	1,430	140	12	18	30 x	10	350	
Princeton University	P-GEM X-3	Annular	20 dia. x 3	850	150	-	30	25	-	400	
	Scooter X-2	Annular	8 dia. x 4	120	5	8	5	10	0	180	Flexible cloth skirt
Reynolds Aluminum Co.	-	Annular	32 x 14	2,500	300	8	12	70 x	-	800	
Spacetronics	-	Plenum	18 x 9 x	800	-	-	4	-	-	200	
	Hydro-Aire	Plenum	32 x 24 x 5	5,300	270	9	5	47 x	-	500	
Valmet Corp.	Kaario V-8	Plenum	14 x 10 x 6	650	18	12	-	38 x	10	4,200	Ram-wing concept
Vickers - (So. Marsten) Co.	Model 3031	Annular	47.5 x 20.1	10,500	1,000	-	18	60 x	-	6,000	Under construction
Wm. Denny & Bros.	-	Annular	-	-	-	-	-	-	-	-	Sidewall skeg

Exhibit 9 - contd.

			Propulsion					Lift						Control			Construction	
Company	Model Name/No	Type of Program	Type	No.	Total Wt. (lb.)	Hp.	Total Thrust (lb.)	Type	No.	Fan O.D. (in.)	Total Flow (lb./sec.)	Fan Total Wt. (lb.)	Facing Direction	Pitch	Yaw	Roll	Type	Material
Aerophysics (USMC)	Gem II	Prototpye	Free props	2	80	300	1,500	Fans	4	55	1,120	348	Forward	Ballast	Fan pitch/rpm	Ballast	Truss	Alum, ply
Aeroneutronics	Utility ven.	Study	Ducted props	2	176	150	1,800	Fans	2	96	720	238	Forward	Diff.jet thick	Fan pitch	Fan pitch	Honeycomb Truss	Alum
Anti-Friction Hull	Hydrokeel	Prototype	Water props	2	400	140	-	Sq. cage blower	2	-	128	-	Upward	-	Skegs	Skegs	-	Ply
Avro	Avrocar	Research	Deflected jet	-	-	-	-	Tip-turbine fan	1	60	550	263	Upward	Def. jet	Def. jet	Def. jet	Webbed beams	Alum st. steel
Bell Aerosystems	Model 2033	Prototype	Water prop	1	195	80	-	Fan	1	54	56	46	Upward	Ballast	Water prop	Skegs	Molded shell	Fiberglass
	Model 2015	Research	Defl.edge flap	-	-	-	-	Fan	1	54	-	46	Upward	Def. edge flap	Def. edgeflap	Def. edge flap	Molded shell	Fiberglass
Bell Helicopter	Scooter	Prototype	Kines., tilt	-	-	-	35	Fan	1	30	27	5	Upward	Int. vane	Side ports	C. G. shift	Monocoque	Fiber
Bertelsen Mfg	-	Prototype	Kines., tilt	-	-	-	-	Fan	1	84	-	100	Upward	Var. fore & aft jets	Var. side jets	Var. side jets	Tubing truss	Alum
Convair	-	Study	Turboprop	4-9	-	-	-	Fans	9-22	-	-	-	Inclined	-	-	-	-	-
Curtiss-Wright	ACM 6-1	Prototype	Side louvers in jet	-	-	-	-	Fans	2	42	130	200	Upward	-	Var. louver opening	Var.louver opening	Box & truss	Alum, fiber
	ACM 2-2	Prototype	Side vents	-	-	-	-	Fans	2	54	240	110	Upward	-	Var. vent	Var. vent	Tubular truss	Alum, fiber
Fletch-Aire	-	Prototype	Side louvers, air bleed	-	-	-	-	Fan	1	51	-	12	Upward	Var.louver	Var. louver	Aileron	Alum tubing	Alum, fabric
Goodyear	-	Research	-	-	-	-	-	Fan	1	21	16	120	Upward	-	-	-	Alum tubing	Alum
Grumman	Getol	Study	Free props	2	-	1,200	-	Fan	1	-	-	-	Upward	-	Diff. prop.	-	-	-
Gyrodyne	55	Prototype	Kines.,tilt	-	-	-	-	Fan	1	24	45	27	Upward	Vane	Vane	Vane	Semi-monocoque	Dural
Hiller	DP-3	Research	Differ. jet	-	-	-	-	Fan	1	9	-	-	Upward	-	-	-	-	-
Hughes	STV	Prototpye	Water props	2	-	-	-	Fan	1	46	84	38	Upward	-	Diff. water screws	-	Wooden	Wood
	DTV	Prototype	Water prop	1	275	80	-	Fan	1	46	54	38	Upward	-	Water prop	-	Wooden	Wood
National Res. Assoc.	GEM III	Prototype	Vanes in main jet	-	-	-	-	Fans	2	38	64	118	Forward	Dumpvalves	Control vanes	Dumpvalves	Box	Alum alloy
	GEM I	Prototype	Vanes in main jet	-	-	-	-	Fans	4	42	40	128	60° up	Throttle	Control vanes			Alum alloy
Princeton University	X-2	Research	Kines.,tilt	-	-	-	-	Fan	1	26	-	3	Forward	Kines.	Vanes in jet	Kines.	Steel tube	Steel fabric
	X-3	Research	Free prop, tilt	1	-	50	20	Fan	1	58	-	12	Upward	Free prop	Free prop	Vanes in slot	Alum ribs	Alum fabric
Spacetronics	Hydro-aire	Prototype	Free prop	1	-	-	-	Fans	2	-	-	-	Upward	-	-	-	Box	Alum
Valmet	V-8	Research	Free prop	1	-	-	180	Prop & ram	1	54	-	-	Forward	Stab. behind prop	Rudder	-	Wooden	Wood
Vertol	GEA	Study	-	-	-	-	-	Fans	2	48	-	560	Upward	-	-	-	-	Dural, fiberglass

Source: Harry Mankuta, Ground Effect Machines Morphology Study, Final Report (ONR Contract 3074(00)), Bell Aerosystems Co. (Report 2017-945002), Buffalo, N. Y., January 1961, pp. 14 & 15; T. E. Sweeney and W. B. Nixon, Some Notes on the P-GEM (Contract DA 44-177-TC-524), Princeton University (Report 537), Princeton, N. J., January 1961, pp. 1-13.

off the air cushion. In the plenum system (which may be compared to an inverted bowl), lifting pressure is created by the pressure rise under the fan at the top of the plenum chamber (bowl). As further noted, several propulsion systems are utilized for achieving movement capability in the listed vehicles. Still others are available or proposed. They include deflected jet, differential edge, free propeller, water propeller, air bleed, turbofan-turbojet, and ducted fan. They fall into three general groups, in which propelling force is provided (1) by a separate propeller or jet— separate propulsion system, (2) by the air that is used to create the cushion — integrated propulsion system, and (3) by a combination of these — mixed propulsion system.

The axial-flow fan arrangement is used almost exclusively in the existing GEM hardware. It is capable of handling large quantities of air at relatively low pressure. Other air-mover arrangements have been proposed or are under study. Control and stability arrangements vary widely. For control, they include systems based on air jets, vanes in jets, kinesthetics, aerodynamic surfaces, air ports, jet air blockage, and fans. For stability, they include a system of flaps on the base plate and a system of auxiliary air jets on the base plate utilizing various layout patterns. Eventual success of the GEM vehicle as a practical means of transport will depend importantly on achievements in the areas of control and stability. Other major system components have to do with planform arrangement, structural arrangement, and materials.

OPERATIONAL ASPECTS

The hydroplane, as amply demonstrated on an operational and experimental basis, is inherently capable of high speeds — up to 50 to 60 knots, and still higher in special cases. The exact upper limit realizable in a particular hydroplane design is a function of operational requirements, governed by the acceptable or allowable mix of speed, range, and payload, by the state of the art, and by economic factors. In general, considered from the standpoint of the present level of hydroplane technology and architecture, designing for a given high-speed capability should present no particular problem.

At low speeds, as shown in Exhibit 10, the hydroplane can be expected to use more power (up to the point where planing starts) than water-displacing vehicles, or vessels, of comparable size and weight. At what point planing starts is not easy to expound upon with precision. It can be started at a speed as low as 10 knots. The exact starting point, it can be recognized, is related to the planing-hull type, the boat weight, the power, and other factors. It is reasonable to consider that a boat is

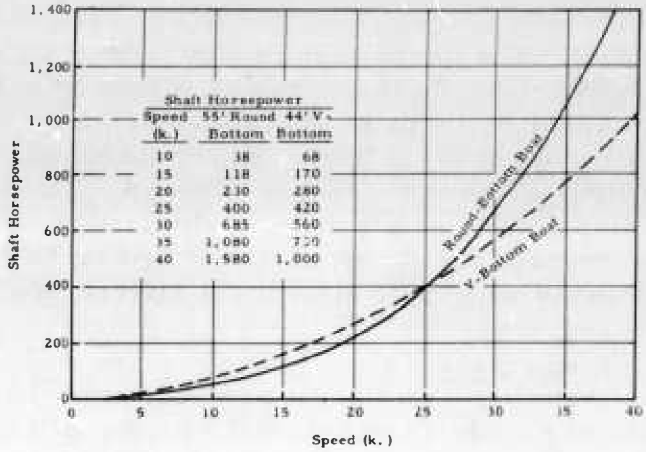

Exhibit 10. Comparison of Shaft Horsepower of Round-Bottom and V-Bottom Boats of Equal Displacement. (Source: Allan B. Murray, "The Hydrodynamics of Planing Hulls", Transactions, Volume 58, 1950, The Society of Naval Architects and Marine Engineers, New York, New York, 1951, p. 658.)

planing when its center of gravity is lifted above its normal "float" position.

Beyond a certain speed in the planing condition, as further evidenced in Exhibit 10, the power requirement becomes rapidly excessive. The size of the power plant imposed may soon become a limiting factor itself. An additional limit on speed is introduced in the form of wave pounding and slamming and water spraying in a seaway, the extent of which depends on hull design, vehicle speed, sea state, and operator skill.

For the most part, hydroplane boats are used for pleasure pursuits, in governmental activities (importantly military), and generally under circumstances justifying high speed. Hydroplane boats are seldom used commercially, and then only for passenger transportation as a rule and hardly ever for cargo transportation. As shown by Gabrielli and von Kármán in their paper,[12] above a certain speed each particular type of vehicle becomes uneconomic and must yield to the next type of vehicle in line. The point is not to confuse speed capability with transportation

[12] G. Gabrielli and Theodore von Kármán, "What Price Speed? - Specific Power Required for Propulsion of Vehicles", Mechanical Engineering, Vol. 72, No. 10, October 1959, pp. 775-781.

efficiency (cost). The cargo ship is slow, but it is at the same time a low-cost bulk carrier. In the case of the hydroplane, speed capability and payload capability (with range capability) pull strongly in opposite directions, for weight is critical. Every pound added takes away from speed, with little or no compromise allowed. The application of the hydroplane principle to an amphibian with land movement capability assumes, of course, the incorporation of retractable-wheel and faired-hull arrangements with the concomitant effects on speed, range, and payload.

The hydrofoil vehicle, examined on an individual basis, has shown itself capable of speeds approaching 80 knots, of ranges in excess of 1,000 miles, and of payloads of up to 15 tons. No single hydrofoil vehicle, past or present, operational or experimental, has combined all three upper limits, or anything near it, in a single package. The three capabilities—speed, range, and payload—as in the case of the hydroplane vehicle, are inextricably woven together, and one is emphasized only at the expense of another. Hydrofoil vehicles currently being developed, planned, or proposed promise to combine the three operational capabilities in question at higher levels than now obtaining and to go beyond the upper limits set forth, specifically in the area of payload.

As in the case of the hydroplane, there is an optimum speed range, below which the power requirement is greater than that for a comparable conventional-hull vehicle (a factor to be considered here is whether the foils are retractable) and above which the power requirement becomes rapidly excessive. In general, the lower limit of this optimum speed range is the point where the hydrofoil vehicle becomes foilborne and the upper limit is where supercavitation sets in. In a recent drag analysis (preliminary) of two high-speed boats, it was shown that a supercavitating craft will require about 2-1/4 times as much power as a subcavitating craft.[13] The latter boat is operating at the upper limit of subcavitation, while the former is well into supercavitation. In either speed category, skilled operator capability is assumed, as a matter explained by the operation of any high-speed vehicle and for hydrofoil vehicles for reasons to be explained.

At this point, it is desirable to review briefly the operational experience of the PT 10, the PT 20, and the PT 50—in particular, the PT 20 hydrofoil boat—since these are the only hydrofoils in the western world with

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[13] J. J. Stilwell, Capt., P. W. Nelson, Lt. Cdr., and W. R. Porter, Lt. Cdr., USN, "Hydrofoils at the Crossroads", Aerospace Engineering, Vol. 20, No. 3, March 1961, pp. 75-76.

actual operational experience. Thereupon, a few words will be said regarding the operational experience obtained in the tests of the FLYING DUKW.

Exhibit 11 presents tabularly the major service areas, routes, and other information relating to the PT 10, the PT 20, and the PT 50 hydrofoil passenger boats. The PT 10 holds the distinction of starting the first

Exhibit 11. Supramar PT 20 and PT 50 Passenger Services.

Year Started	Passenger Routes—Location and Length	Boat and No.
	Italy-Switzerland	
1953	Lago Maggiore (33 mi.)	PT 10 (1)
	Italy-Sicily	
1956	Messina/Reggio di Calabria (10 mi.)	PT 20 (1)
1957	Messina/Taormina (26 mi.)	PT 20 (1)
1957	Messina/Liparian Islands/Palermo (115 mi.)	PT 20 (1)
1958	Lago di Garda (35 mi.)	PT 20 (1)
1959	Venice/Trieste (60 mi.)	PT 20 (1)
1960	Naples/Capri/Ischia (20 mi.)	PT 50 (2)*
	Norway	
1960	Stavanger/Bergen (110 mi.)	PT 50 (2)*
	Sweden-Finland	
1960	Stockholm/Mariehamn (78 mi.)	PT 50 (1)
	Venezuela	
1959	Maracaibo/Cabimas (20 mi.)	PT 20 (3)
	Argentina-Brazil	
1960	Montevideo/Buenos Aires (130 mi.) (In preparation)	PT 50 (2)
	Puerto Rico	
1961	(In preparation)	PT 20 (1)

*One on order.

hydrofoil passenger service. This service was begun in 1953 on Lago Maggiore between Locarno in Switzerland and Arona and Pallanza in Italy. The route mileage is 33 miles and the block-to-block speed is 47 knots. Service has been maintained under all conditions of weather,

including occasionally waves running to 4 feet in height. The PT 10 is capable of carrying 28 passengers. To date, hydrofoil boats have not been used commercially in the transportation of cargo.

In service, the PT 20 (shown in Exhibit 12) has operated at sustained high speeds (35 to 50 knots), over different stage lengths (10 to 60 miles), and under heavy load conditions (50 to 100 percent). On the Messina/ Reggio di Calabria run (10 miles) a trip frequency as high as 11 round trips per day per boat has been achieved, in which the in-transit time has been cut to one-quarter that of the displacement-hull ferries. Though not designed for long-distance travel, the PT 20 has made several long trips for demonstration and experimental purposes along the coast of Italy, one from Messina to Naples and several across the open sea, the longest of which was from Italy to Greece, involving a round trip of 1,600 nautical miles.

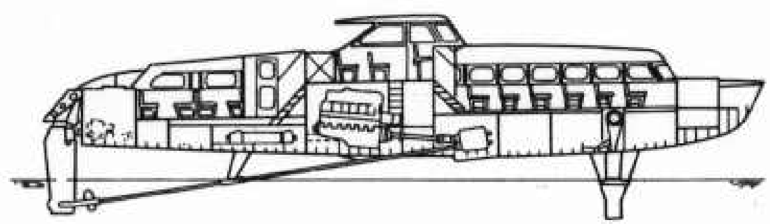

Exhibit 12. Sectional Drawing of the Supramar PT 20.

It has operated foilborne in seas with waves running 13 feet in height. In the Caribbean, a PT 20, caught in the fringe area of a hurricane, proceeded in half-foilborne position in waves averaging 16 feet in height. On another occasion, a PT 20, passing through the Straits of Otranto, was forced down by waves nearly 13 feet high, but of short length, and was able to maintain an average speed of 15 knots. The PT 20 has performed with considerably less pitch, heave, and roll motions than like-size conventional boats, even in rough seas. As found, in rough seas the motion is too frequent and small to cause seasickness. At rest, the foils act as stabilizers, reducing motion in this way. Sea-riding qualities, it may be recognized, are a function of sea state and wave type (in turn, a function of area to some extent), boat length, foil-stabilizer system, and operator skill. Hydrofoil boats are able to

maintain a higher speed in a seaway than waterborne craft. The problem of buffeting with high-speed operation of hydroplanes in a seaway has already been indicated.

The time consumed in decelerating the PT 20 from full speed to sitting down (hull bottom on water) is between 6 and 7 seconds. Less than 25 seconds is required to bring the boat to a complete halt, using the propeller only after the boat is down to a slow speed. The corresponding distance from full speed to complete halt is about 650 feet. The turning radius is between 350 and 500 feet running at 40 knots. In all turns, the boat banks properly inboard. At 30 knots, the turning radius is approximately 100 feet. The rudder response is rapid, providing rapid maneuvering capability in open seas to avoid collision with debris and other floating objects and damage to the foils, and in terminal areas to move around boats and other floating objects. In foilborne operation, the wave systems created by the hydrofoil boat are small, combining with maneuverability to promote high-speed capability in the terminal area. In such operations, operator skill is understandably important.

The foils (medium steel shells) have proved to be reliable and capable of withstanding heavy impacts, as evidenced by boats running aground on several occasions and being able to continue and, on one occasion, by a boat colliding with a pier and causing only minor deformation. With retractable foil systems, this type of danger is avoided or greatly reduced. In open-sea operations, thousands of hours have been accumulated against the foils without serious damage from floating objects. Driftwood, tree trunks, and other debris up to about 8 inches in diameter are, as a general rule, cut in two or pushed aside. Shearing capability for separating foils on heavy impact with floating objects to prevent damage to the boat is suggested. In four boats built for the Shell Petroleum Company, from a special design of the PT 20, for use on Lake Maracaibo, Venezuela, to transport personnel between shore points and offshore drilling platforms, the bridge was located in the foreship in order to provide better operational vision in the tropical areas, where driftwood is prevalent. Propellers were also specially protected.

Boats are lifted out of the water every 2 or 3 months for cleaning, including foils, hull, and bottom. In warm-water areas, where the marine growth is intense, boats are removed from the water at more frequent intervals. This may be as often as every 2 or 3 weeks in such areas as the Caribbean, as reported by an owner of a PT 20 boat.[14] Foils are cleaned at separate and very frequent intervals by aqua-lung

[14] Interview, 12 June 1961.

divers, as often as every 2 or 3 days. Disregarding major overhaul, maintenance of the foils consumes about 25 percent of the total maintenance time spent on the boats, with maintenance time (not including major overhaul) averaging about 8 hours per 100 hours of running time. The foils in question are nonretractable. The use of retractable foils can be expected to change this picture. In any case, clean foils and a clean hull are essential to early take-off and take-off per se.

The experience gained with the PT 50, a later and larger version of the PT 20, is more limited than that gained with the latter, but it has been along the same lines. The PT 50 prototype was built in 1958, and became operational in 1960. Some twenty PT 20 boats and five PT 50 boats have been built or are nearing completion.

In tests,[15] the FLYING DUKW achieved a take-off at 11 to 12 knots, a maximum foilborne speed of 30 knots, and a boating, or displacement, speed of about 7 knots. Turns were accomplished at a speed of 22 to 25 knots in a turning circle of approximately 250 feet, with some difficulties encountered. Landing (power off, full speed to boating glide) was accomplished in a distance of 150 to 200 feet (estimated), and power-on forced landing in 50 to 75 feet. Take-off, it was found, was adversely affected by an increase in drag resulting from foil corrosion after a week in the water and the marginal power available due to the high turbine-inlet air temperatures, which ranged from 85° to 90° F. in the test area (Florida coast). Boating and take-off were also limited by the drag of the wheels and the undercarriage. When wheels and undercarriage were removed, drag was reduced 10 percent, and by an additional 15 percent when the underside was faired.[16]

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[15] Modification and Testing of a World War II DUKW, Vol. 1, (Contract DA-19-059-ORD-2482), Avco Corp. (Lycoming Div.), Stratford, Conn., 30 November 1960, 28 pp., with drawings, charts, and appendixes.

[16] A hydroplane model with the same overall dimensions of the DUKW (model) and a similar hydrofoil arrangement was tested in a towing tank to determine take-off power requirements and drag characteristics. It was found that take-off power for the planing hull, the DUKW model with no wheels and faired bottom, and the conventional DUKW (with wheels) was respectively 165, 250, and 290 effective horsepower (37 percent savings between the first and second situation and 43 percent between the first and third). Source: Ibid., Appendix LR 695.

No speed, range, or payload capability tests were conducted as such.

Performance of the electronic stabilizer system, as stated in the report of tests, indicated that the system would provide stable flight with certain modifications and changes. Operationally described, the system measured the water height ahead of the DUKW and transmitted electrically the acquired intelligence to an autopilot, which interpreted the intelligence and sent corrective signals to electrohydraulic servo valves at each front strut. Here the signals were transformed to a hydraulic force to change the foil angles of attack, according to the changes in wave heights, to provide controlled and stabilized flight.

The GEM vehicle, limited to experimental applications, has not produced sufficient information upon which to draw valid conclusions regarding operational capabilities, examined on an experience basis. It works, as exemplified by the crossing of the English Channel in July 1959 by the British SRN-1.[17] See Exhibit 13. On that trip, the SRN-1 attained a maximum velocity of 23 knots. The mean speed was 13.8 knots. It carried a payload of approximately 1,100 pounds, comprised of crew (3) and fuel. It consumed 79 gallons of fuel, stopping 2 miles short of Dover to pick up 8 additional gallons. The course distance (Calais to Dover) was 25 nautical miles. En route, it encountered a 5-knot wind and swells up to 80 to 100 feet long and about 2 feet from trough to crest, with a superimposed chop of about 9 inches.

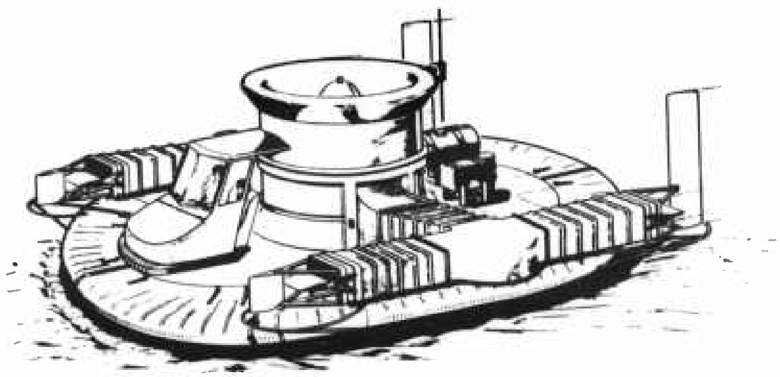

Exhibit 13. British SRN-1 Experimental Craft.

[17] C. S. Cockerell, R. Stanton Jones, and P. Lamb, Lt. Cdr., "Some Remarks on the English Channel Crossing of the Hovercraft on July 25, 1959", Symposium on Ground Effect Phenomena, 21-23 October 1959, Princeton University, Princeton, N. J., pp. 193-201.

At one point in the journey, it was forced statically into the water to avoid collision with a small boat. Operating altitude was about 1-1/2 feet. Arriving at its destination, it moved easily across the beach to demonstrate amphibious capabilities.

Theoretically considered, the GEM vehicle is capable of speeds of 80 to 100 knots and much higher. At very high speeds, aerodynamic streamlining and lift become pertinent factors. Range and payload capabilities are as great as those provided by air transports currently flying and possibly could be much greater. As with the hydroplane and hydrofoil, speed, range, and payload are variable factors. The operating altitude and the planform area are additional variables of very fundamental importance. A small planform area (small GEM vehicle) will necessitate a high power/weight ratio and very truly so at a high operating altitude. Conversely, an increased planform area and reduced operating altitude will sharply reduce the power requirements. At the same time, it may be recognized that a minimum operating altitude is required to traverse maximum sea waves and to be safe. Such need is even more pronounced for operation over the land. In either circumstance, high-speed operation close to the earth's surface emphasizes a need for skilled operators. It is not clear at this time whether there is an optimum speed range for the GEM vehicle, such as there is in the cases of the hydroplane and the hydrofoil. In one study,[18] it was indicated that the most economic speed was between 80 and 100 knots at an operating altitude of 0.2 and 0.7 meter. Down at 40 knots, the fuel economy was determined to be quite poor. The GEM vehicle under examination was a 30-ton Swedish attack craft (design project).

In more recent operations (experimental), a GEM vehicle attained a speed of 56 miles per hour over a measured course. Another GEM vehicle is reported to have reached 75 miles per hour.

CONCEPTUAL VEHICLES

The hydroplane, hydrofoil, and ground-effect principles, and their application, have been examined in a general way. In the technical area, configurations, propulsion systems, structures, and materials

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[18] Olle Ljungstrom, GEM Design Philosophy for an Overwater, Over-Ice Vehicle, a paper presented at the 29th Annual Meeting of the Institute of the Aerospace Sciences, New York, New York, 23-25 January 1961, p. 14 and Figure 8.

have been identified. In the operational area, speed, range, payload, and other operational aspects have been surveyed. Based on the information that has been revealed and the supporting estimates and calculations,[19] a group of conceptual vehicles embodying the principles in question are established for purposes of economic analysis. These vehicles and the pertinent technical and operational details are shown in Exhibit 14. A schedule of major component weights for the conceptual vehicles is contained in Exhibit 15 (page 35). For analytic and comparative purposes, the LARC-5, the LARC-15, and the BARC are included in both exhibits with technical and operational data and weights. The balance of this section is given over to a brief discussion of the contents of Exhibits 14 and 15.

As envisioned, the conceptual vehicles are designed for the movement of military cargo from ship to shore and inland over varying water stage distances, specifically (for purposes of this analysis) 1, 2, 3, 4, 5, 10, 20, 30, 40, and 50 miles. The land stage distances are 0 miles and 5 miles. Such stage distances are predicated on a consideration of operations in a nuclear climate. All conceptual vehicles employ gas-turbine engines, which combine high power with lightness and compactness and provide power for water and land movement. Light materials, essentially aluminum and fiberglass, are used extensively in the hull construction and elsewhere. As in the case of aircraft, weight is critical.

Both the hydroplane and the hydrofoil vehicles utilize water propeller arrangements with retraction capability for surfing and land operations. The GEM vehicles utilize fan and ducted-propeller arrangements to pro-

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[19] The estimates and calculations made in connection with the conceptual vehicles make important use of data contained in a recent hydroplane design study (Engineering Study and Investigation To Determine and Demonstrate the Most Technically Feasible Concept of a 5 Ton Wheeled Amphibious Lighter Capable of Water Speeds in Excess of 25 MPH, Final Report, Contract DA 44-177-TC-604, Borg-Warner Corp., Kalamazoo, Mich., December 1960), various hydrofoil amphibian proposals (not identified for proprietary reasons), and a GEM morphology study (Harry Mankuta, Ground Effect Machines Morphology Study, Final Report, Contract Nonr 3074(00), Bell Aerosystems Co., Buffalo, N. Y., January 1961). The last-mentioned item, which was prepared for the Office of Naval Research, presents a quick method, developed with the use of the IBM 704 digital computer, for estimating (with the assistance of a carpet chart) GEM vehicular performance, varying the size, power, speed, range, payload, operating altitude, and gross weight.

Exhibit 14. Real and Conceptual Vehicles - Technical, Operational, and Other Details.

Vehicle	Application	Crew Grade & No.	Length (ft.)	Width (ft.)	Height (ft.)	Power Type	Power Hp., max.	Hull Material
LARC-5	Amphibious	E-4(1), E-3(1)	35.0	9.0	9.2	Gasoline	270	Alum
LARC-15	"	E-4(1), E-3(1)	45.0	12.5	13.0	Gasoline	540	Alum
BARC	"	E-7, -5, -4, -3(1 ea)	62.5	26.6	19.4	Diesel	800	Steel
Hydroplane I	"	E-6(1), E-3(1)	35.0	10.0	13.0	Turbine	750	Alum
Hydroplane II	"	E-6(1), E-3(1)	40.0	13.0	13.0	"	1,500	"
Hydroplane III	"	E-7(1), E-4(1)	56.0	14.0	14.0	"	2,000	"
Hydroplane IV	"	E-7(1), E-4(1)	65.0	15.0	14.0	"	3,000	"
Hydrofoil I	"	E-6(1), E-3(1)	35.0	10.0	10.0	"	550	"
Hydrofoil II	"	E-6(1), E-3(1)	35.0	10.0	10.0	"	900	"
Hydrofoil III	"	E-7(1), E-4(1)	45.0	12.0	14.0	"	1,050	"
Hydrofoil IV	"	E-7(1), E-4(1)	45.0	12.0	14.0	"	1,750	"
GEM I	"	E-6(1), E-3(1)	64.0	32.0	15.0	"	2,400	"
GEM II	"	E-6(1), E-3(1)	40.0	20.0	11.0	"	9,700	"
GEM III	"	E-7(1), E-4(1)	64.0	32.0	15.0	"	4,000	"
GEM IV	"	E-7(1), E-5(1)	64.0	32.0	15.0	"	10,000	"
GEM V	"	E-6(1), E-3(1)	64.0	32.0	15.0	"	5,800	"
GEM VI	"	E-6(1), E-4(1)	40.0	20.0	11.0	"	5,300	"
GEM VII	"	E-7(1), E-4(1)	64.0	32.0	15.0	"	10,700	"
GEM VIII	"	E-7(1), E-5(1)	64.0	32.0	15.0	"	5,200	"

Exhibit 14, contd.

Vehicle	Speed, Max. (m. p. h.) Land	Speed, Max. (m. p. h.) Water	Altitude (ft.)	Range, Water (mi.)	Payload (tons)	Weight,* Light (tons)	Weight, Gross (tons)	Hp. ÷ W_g**	Payload (% of W_g)
LARC-5	23.7	9.0	n. a.	65	5	9.0	14.6	18.5	34.2
LARC-15	23.5	9.0	"	130	15	16.5	33.1	16.3	45.3
BARC	14.0	7.0	"	150	60	97.9	160.4	5.0	37.4
Hydroplane I	25.0	25.0	"	200	5	10.5	17.5	42.9	28.6
Hydroplane II	25.0	35.0	"	"	5	12.7	20.0	75.0	25.0
Hydroplane III	20.0	25.0	"	"	15	22.4	42.5	47.1	35.3
Hydroplane IV	20.0	35.0	"	"	15	26.6	47.5	63.2	31.6
Hydrofoil I	35.0	30.0	"	"	5	11.3	17.5	31.4	28.6
Hydrofoil II	35.0	40.0	"	"	5	10.0	17.5	51.4	28.6
Hydrofoil III	25.0	30.0	"	"	10	22.6	35.0	30.0	28.6
Hydrofoil IV	25.0	40.0	"	"	10	22.1	35.0	50.0	28.6
GEM I	40.0	40.0	3.0	"	5	8.2	17.0	141.2	29.4
GEM II	80.0	80.0	5.0	"	5	8.1	20.5	473.2	24.4
GEM III	40.0	40.0	3.0	"	10	9.4	25.5	156.9	39.2
GEM IV	40.0	80.0	5.0	"	10	17.7	30.5	327.9	32.8
GEM V	40.0	40.0	5.0	"	5	10.6	24.5	236.7	20.4
GEM VI	80.0	80.0	3.0	"	5	5.9	15.0	353.3	33.3
GEM VII	40.0	40.0	5.0	"	10	13.7	40.0	267.2	25.0
GEM VIII	80.0	80.0	3.0	"	10	10.3	24.5	212.2	40.8

*Light weight = gross weight less crew, fuel, and payload.
**W_g = gross weight.

vide air to the annular jet and for forward motion. The hydroplane hull arrangements are based on the inverted V-bottom planing-hull type. The hydrofoil hull arrangements are along the lines of those of the LARC-5 and the LARC-15. The hydroplane and hydrofoil hulls are structured for planing and foil operation. Hydraulically actuated wheel retraction systems are employed by the hydroplane and hydrofoil vehicles, with faired bottom provisions in the case of the former. The foils employed by the hydrofoil vehicles are also retractable. The forward foil is of the surface-piercing type; the rear, of the submerged type. The rear foil forms a part of the water propeller arrangement. Wheel and foil systems are obviated in the case of the GEM vehicles. Sea-going radio and radar equipment is included for all conceptual vehicles.

The lengths and widths given for the GEM vehicles appear to be excessive, considering the length and width dimensions of the LARC's and the BARC and transportability and accessibility requirements generally. They are required, however, since any lesser dimensions would serve automatically to put the GEM vehicles out of the race at the start. On closer examination, the GEM dimensions do not appear to be unreasonable. The BARC is almost as large in the case of one set of GEM dimensions given, namely, 64 feet by 32 feet. Moreover, considering the operational experience obtained with the BARC in the Canadian Arctic and currently at Taiwan,[20] limited use has been made of its land movement capability. Land penetration in both areas has averaged less than 1/4 mile from the beach, with land speeds of only 2 or 3 miles per hour. It would appear that land accessibility in the particular operational situations considered is not critical or is needed only to the extent reported. On the other hand, the size and weight of the BARC may indeed be limiting factors.

The complement given reflects differences in responsibility arising from differences in vehicular speed and investment. Unskilled labor may be employed in the case of the LARC's and the BARC, though there are cogent reasons dictating against such employment. For high-speed large-investment vehicles, such as those represented by the

[20] After Action Report, Subport Frobisher, 1955, op. cit.; After Action Report, Subport Frobisher, 1956, op. cit.; and the following letter reports: BARC Information Letter, December 1960(U), BARC Information Letter, January 1961(U), and BARC Information Letter, March 1961(U), dated respectively 10 January 1961, 7 February 1961, and 12 April 1961, from Hq, Army Section, Military Assistance Advisory Group, Republic of China, to Army Chief of Transportation.

conceptual vehicles, an alert, responsible, and skilled crew is mandatory, it goes without saying.

The maximum water speeds given for the conceptual vehicles, which may be considered for reasons of analytic convenience and simplicity to represent averages of unloaded and loaded rates of speed (actually, or nearly, so in the case of the rates given for the LARC's and the BARC), are realistic, considering what is technically possible and operationally feasible. Beyond the cited water speeds, power requirements can be expected to soar. The problem of supercavitation in connection with hydrofoils and its impact on power requirements have already been discussed. The conceptual GEM vehicles, already manifesting high power requirements, might derive some benefit from higher speeds as a consequence of aerodynamic lift. In general, however, any increase in power beyond those given for the conceptual vehicles—and the real vehicles as well—would impose prohibitive limitations. Operationally higher water speeds can be expected to introduce substantial problems relating to safety and attrition.

The maximum land speeds given are technically feasible, considering among other factors the power available as a result of the water movement capability. Operationally, however, the maximum land speeds are not so readily employable as the maximum water speeds. Whereas the sea path is wide, straight, and uniform, the land path, including both cross-country routes and developed roadways, is characterized by a wide variety of natural and man-made environmental conditions that act to limit speed or to add to in-transit time. Accordingly, for purposes of this analysis, a land speed of 10 miles per hour, covering both unloaded travel and loaded travel, is adopted in lieu of the maximum land speeds given in Exhibit 14.

Altitude applies only to the GEM vehicles. The operating altitude selected has a profound effect on power requirements. As shown in the next to the last column in Exhibit 14, the amount of horsepower per ton of gross vehicle weight is increased from 141.2 to 236.7 for GEM vehicles I and V, with an increase in operating altitude from 3.0 to 5.0 feet. The two operating altitudes given in Exhibit 14, in addition to demonstrating the impact of altitude on power, consider to some extent different average wave height conditions that might be anticipated in world-wide operations and the feasibility of operating at very high speed over water as a function of height.

The range given for the conceptual vehicles (200 miles) assumes operation in a nuclear climate and reflects what is practical otherwise.

The payloads given for the conceptual vehicles are in keeping with what is technically possible and operationally feasible. As shown in Exhibit 14, they are 5 and 15 tons for the hydroplane vehicles and 5 and 10 tons for the hydrofoil and GEM vehicles. Light weight (gross weight less crew, fuel, and payload) varies from a high of 26.6 tons for the Hydroplane IV to a low of 5.9 tons for the GEM VI. These vehicles also register the highest and lowest gross weights for the list of conceptual vehicles, being 47.5 tons in the case of the Hydroplane IV and 15.0 tons for the GEM VI. The amount of horsepower per ton of gross vehicle weight varies from a low of 30.0 for the Hydrofoil III to a high of 473.2 for the GEM II. Hp./W_g is consistently above 100 for the GEM vehicles and below 100 for the hydroplane and hydrofoil vehicles. Payload as a percentage of gross weight varies from a high of 40.8 for the GEM VIII to a low of 20.4 for the GEM V. Considering both hp./W_g and payload percentage, the LARC's and the BARC are by far the best off.

Turning to Exhibit 15, the component weight systems considered are crew, fuel, payload, hull, wheel, foil, engine, and other. The crew weights given are based on the number of persons making up the assigned crew times a standard weight of 200 pounds per person. Fuel weights for the conceptual vehicles (gas-turbine engines) are based on a fuel consumption rate of .6 pound/horsepower/hour. This rate was derived from a plot of specific fuel consumption rates constructed for a number of gas-turbine engines, as shown in Exhibit 16. The rate is on the liberal side below 3,000 horsepower and on the conservative side above 3,000 horsepower. Based on present gas-turbine trends, fuel consumption rates can be expected to continue to improve in both horsepower ranges. For the moment, the rate of .6 pound/horsepower/hour represents a good overall working figure for purposes of this study. As evidenced in Exhibit 15, it can be readily seen that the fuel weights are generally very high for the GEM vehicle, particularly in the case of one GEM vehicle; moderately high for the hydroplane vehicles, especially for Hydroplanes III and IV; and comparatively low for the hydrofoil vehicles. The payload column requires no explanation.

Hull weights vary from a high of 20,900 pounds for Hydroplane IV to a low of 5,100 pounds for GEM VI. As a percentage of gross weight, hull weights run 23 percent for Hydroplanes I and II, 22 percent for Hydroplanes III and IV, 18 percent for Hydrofoils I and II, 16 percent for Hydrofoils III and IV, and 24 percent for the GEM vehicles as a whole. The LARC-5, the LARC-15, and the BARC hull weights as a percentage of gross weight are 15, 11, and 22 percent respectively. Wheel weights, which comprise all weights involving land movement capability (including wheel rims, tires, hydraulic lifts, power transmission, etc.),vary from

Exhibit 15. Weight Schedule.

Vehicle	Crew	Fuel	Payload	Hull	Wheel*	Foil	Engine (only)	Other**	Total
	Component Weight Systems (lb.)								
LARC-5	400	850	10,000	4,350	7,150	-	1,300	5,200	29,250
LARC-15	600	2,650	30,000	7,700	14,050	-	2,350	8,900	66,250
BARC	800	4,300	120,000	71,500	58,000	-	10,450	55,750	320,800
Hydroplane I	400	3,600	10,000	8,000	9,500	-	400	3,100	35,000
Hydroplane II	400	4,150	10,000	9,200	10,800	-	750	4,700	40,000
Hydroplane III	600	9,600	30,000	18,700	19,600	-	1,000	5,500	85,000
Hydroplane IV	600	11,250	30,000	20,900	21,900	-	1,500	8,850	95,000
Hydrofoil I	400	2,100	10,000	6,300	8,800	4,600	300	2,500	35,000
Hydrofoil II	400	2,650	10,000	6,300	8,800	4,600	450	2,600	35,800
Hydrofoil III	600	4,200	20,000	11,200	15,400	10,500	550	7,550	70,000
Hydrofoil IV	600	5,250	20,000	11,200	15,400	10,500	900	7,650	71,500
GEM I	400	7,200	10,000	11,000	-	-	1,200	4,200	34,000
GEM II	400	14,500	10,000	6,000	-	-	4,850	5,250	41,000
GEM III	600	12,000	20,000	13,200	-	-	2,000	3,500	51,300
GEM IV	600	15,000	20,000	14,700	-	-	5,000	5,700	61,000
GEM V	400	17,400	10,000	13,200	-	-	2,900	5,100	49,000
GEM VI	400	8,000	10,000	5,100	-	-	2,650	3,950	30,100
GEM VII	600	32,100	20,000	16,900	-	-	5,350	5,050	80,000
GEM VIII	600	7,800	20,000	13,200	-	-	2,600	4,800	49,000

*Includes all weights (wheel rims, tires, power transmission, etc.) contributing to land mobility.

**Includes marine drive, electrical, control, communication, and navigation system weights and other weights not identified otherwise.

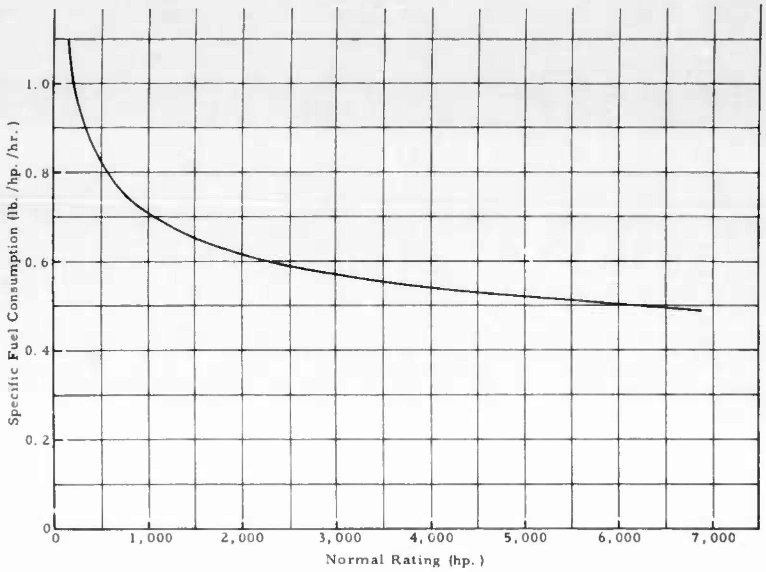

Exhibit 16. Fuel Consumption Rates for a Number of Gas-Turbine Engines. (Reference: "Gas Turbine Specifications - 1961", Gas Turbine, Vol. 2, No. 1, Jan-Feb 1961, pp. 15-26)

22 to 27 percent of the vehicular gross weights. The percentage figures for the LARC-5 and the LARC-15 are 25 and 20 percent respectively. The percentage figures for the conceptual vehicles, namely, the hydroplane and hydrofoil vehicles, are higher, since their wheel arrangements incorporate retraction capability. Foil weights, involving only the hydrofoil group of conceptual vehicles, are 13 percent of the gross weight for Hydrofoils I and II and 15 percent for Hydrofoils III and IV. The larger percentage is attributable to the increased foil area structural requirements for the larger hydrofoil vehicle. In effect, compared to the GEM vehicles, the wheel and foil weights are penalty weights, running a strong 25 percent in the case of the hydroplane vehicles and almost 40 percent in the case of the hydrofoil vehicles.

The engine weights shown in Exhibit 15 are calculated on the basis of one-half pound of engine weight per one horsepower, or .5 pound/horsepower. This rate is perhaps optimistic, but it is not out of line considering

present weight-to-power trends and ratios obtainable in some presently available gas-turbine engines, which range up as high as 5 horsepower per pound of engine weight. The column entitled "Other" is a catchall column. It includes miscellaneous equipment, instruments, controls, electrical wiring, radio sets, and other equipment and weights not included elsewhere in the weight schedule.

PART THREE. ECONOMIC ANALYSIS

The determination of the economic characteristics of conceptual vehicles, not unlike the determination of the technical and operational characteristics of such vehicles, is predicated on a combination of guesswork, estimates, and calculations. If we have managed a good determination, useful information has been produced. Such information, however, will not demonstrate the economic impact of the concerned vehicles if it is developed without regard to the job to be done, pertinently, ship-to-shore cargo movement.

Movement may involve one kind of cargo or a mixture of cargo, 1,000 tons or 100,000 tons of cargo, a 1-day unloading operation or an operation lasting several days, inland movement via amphibians, and varying stage lengths and sea conditions. Considered independently of the job to be done, the conceptual amphibian may evidence very favorable characteristics; but job-rated, just the opposite characteristics may be manifested. We need, then, to establish a hypothetical, but realistic, lift requirement for the real and conceptual vehicles under examination and to determine how well, or badly, they fair economically in carrying out the assigned lift task, measured in terms of capital investments, ton-mile costs, and other economic yardsticks.

Accordingly, there is established for the purposes of economic analysis a daily lift requirement of 5,040 tons of cargo and a 20-hour working day. The tonnage represents the total cargo discharge rate of seven 5-hatch cargo ships during the specified number of working hours per day at 7.2 tons per hatch per hour.[21] Further, there is established a land stage distance of 5 miles and the following water stage lengths, previously given on page 29: 1, 2, 3, 4, 5, 10, 20, 30, 40, and 50 miles. For the purposes of this analysis, the service life of any vehicle is assumed to be 5,000 operating hours. A vehicle is considered to be operational only while it is in motion. At all other times, engines are considered to be in shut-down condition. The 24-hour day in the

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[21] The hatch rate, 7.2, is a mean rate, based on 2,285 hatch hours and 16 ships. See Analysis of Means for Moving Logistic Cargo From Ship to Shore (U), Technical Memorandum ORO-T-361, Operations Research Office, The Johns Hopkins University, Chevy Chase, Maryland, November 1957, p. 106.

life of any real or conceptual vehicle comprises rest, maintenance, repair, and refueling during the 4-hour "off" period and a series of work cycles (round trips) during the 20-hour "on" period (each cycle comprised of maneuvering, loading, and unloading times in the ship-side and shoreside terminal areas; acceleration and deceleration times; maximum velocity travel times; surfing in and out times; and land movement times). For convenience and simplicity, refueling required during the "on" period is considered to be accomplished during loading or unloading. Each vehicle is capable of making so many round trips per working day. The fundamental question to be answered at the outset is, how many vehicles of each type or kind are required to move 5,040 tons of cargo daily for each water stage length and for each water stage length with a 5-mile land stage length added. With this question answered, the balance of the economic analysis becomes an easy matter.

NUMBER OF VEHICLES

To determine the number of real and conceptual vehicles required for each water stage length to move 5,040 tons of cargo daily, the following model (mathematical) system was developed:

$$T = \sum_{i=1}^{12} t_i$$

where

T = total round trip time, in minutes
$t_1 t_2$ = shipside maneuvering and loading times
$t_3 t_{10}$ = acceleration times, V_o (zero velocity) to V_{max}
$t_4 t_{11}$ = travel times, V_{max}
$t_5 t_{12}$ = deceleration times, V_{max} to approximately V_o
$t_6 t_9$ = surfing in and out times
$t_7 t_8$ = shoreside maneuvering and unloading times

and

$$N = \frac{L}{20\left(\frac{60P}{T}\right)}$$

where

N = total number of vehicles required to lift 5,040 tons daily
L = total daily lift requirement (5,040 tons)
P = payload capability of individual vehicle, in tons

and whereas

$$\frac{60P}{T} = \text{hourly cargo delivery rate for one vehicle, in tons}$$

$$20\left(\frac{60P}{T}\right) = \text{20-hour cargo delivery rate for one vehicle, in tons}$$

$$\frac{5,040}{20\left(\frac{60P}{T}\right)} = \text{total number of vehicles required to lift 5,040 tons daily.}$$

Component times (t_1 through t_{12}) are shown graphically in Exhibit 17.

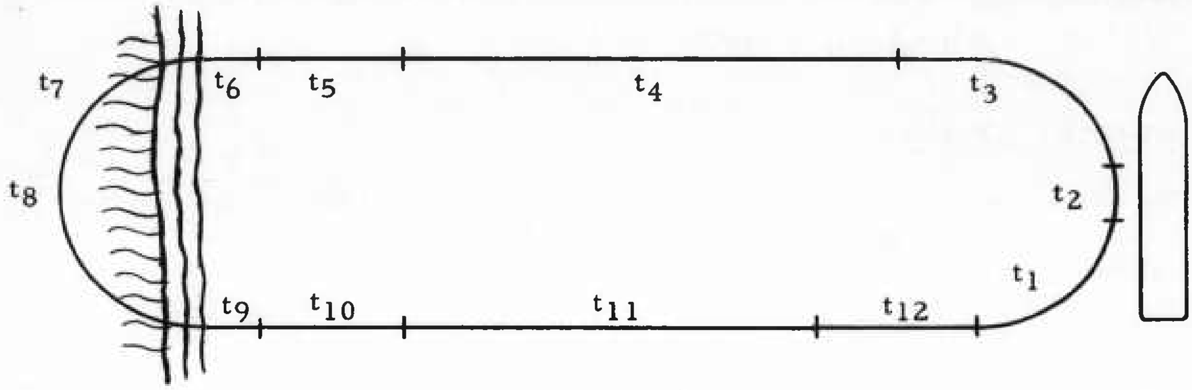

Exhibit 17. Work Cycle, Time Components.

The assigned units of times are given in Exhibit 18. Loading times, t_2, are based simply on 41.7 minutes for each 5 tons of vehicular lift capability and 10 minutes for each unit of unloading time, t_8. Terminal maneuvering times, t_1 and t_7, are empirically constructed and reflect, essentially, differences in vehicular sizes, as do the surfing in and out times, t_6 and t_9. Acceleration and deceleration times—t_3, t_{10}, t_5, and t_{12}—are similarly constructed, drawing on actual and analogous operational experience, full-scale and scaled model tests, theoretical literature, and expert opinion. They are, at best, estimates. Little or no acceleration and deceleration time data, developed on the basis of a measured course, are available. Each trip, it should be noted here, comprises two units of each. t_4 or t_{11} times in Exhibit 18 represent a full mile of travel at maximum velocity. The last column in Exhibit 18 gives travel time at maximum velocity for 1 mile less distances

Exhibit 18. Schedule of Times (in minutes).

Vehicle	Terminal (Shipside) Load t_2	Terminal (Shipside) Maneuver t_1	Interface (Surfing) In t_6	Interface (Surfing) Out t_9	Terminal (Shoreside) Unload t_8	Terminal (Shoreside) Maneuver t_7	Accel. t_3 or t_{10}	Decel. t_5 or t_{12}	Travel, V_{max}, Add. Miles t_4 or t_{11}	Travel, V_{max}, 1-Mi. Water Stage -
LARC-5	41.667	4.000	3.000	2.000	10.000	4.000	.756	.252	6.667	6.160
LARC-15	125.000	6.000	3.000	3.000	30.000	6.000	1.010	.316	6.667	6.000
BARC	500.000	12.000	6.000	6.000	120.000	10.000	1.620	.486	8.571	7.514
Hydroplane I	41.667	4.000	3.000	3.000	10.000	4.000	.318	.182	2.400	2.149
Hydroplane II	41.667	4.000	4.000	4.000	10.000	4.000	.259	.162	1.714	1.503
Hydroplane III	125.000	6.000	4.000	4.000	30.000	6.000	.635	.227	2.400	1.968
Hydroplane IV	125.000	6.000	4.000	4.000	30.000	6.000	.520	.195	1.714	1.357
Hydrofoil I	41.667	4.000	4.000	3.000	10.000	4.000	.378	.151	2.000	1.734
Hydrofoil II	41.667	4.000	4.000	3.000	10.000	4.000	.340	.142	1.500	1.258
Hydrofoil III	83.333	6.000	4.000	4.000	20.000	5.000	.530	.189	2.000	1.640
Hydrofoil IV	83.333	6.000	4.000	4.000	20.000	5.000	.455	.170	1.500	1.187
GEM I	41.667	6.000	3.000	3.000	10.000	5.000	.170	.170	1.500	1.329
GEM II	41.667	4.000	3.000	2.000	10.000	4.000	.284	.284	.750	.466
GEM III	83.333	6.000	3.000	3.000	20.000	5.000	.170	.170	1.500	1.329
GEM IV	83.333	6.000	3.000	3.000	20.000	5.000	.284	.284	.750	.466
GEM V	41.667	6.000	3.000	3.000	10.000	5.000	.170	.170	1.500	1.329
GEM VI	41.667	4.000	3.000	3.000	10.000	4.000	.284	.284	.750	.466
GEM VII	83.333	6.000	3.000	3.000	20.000	5.000	.170	.170	1.500	1.329
GEM VIII	83.333	6.000	3.000	3.000	20.000	5.000	.284	.284	.750	.466

corresponding to the acceleration and deceleration times given. Thus the travel time one way for any water stage length is the sum of one unit of t_3 or t_{10}, one unit of t_5 or t_{12}, one unit of t_4 or t_{11} for each mile of the water stage length less 1 mile, and one unit from the last column. Maximum velocities for all vehicles, upon which the concerned time units are based, are shown in Exhibit 14. The cited velocities, as already stated, apply to both loaded and unloaded travel.

The trip time for each vehicle and for each water stage length in ship-to-shore movement is shown in Exhibit 19. The trip time with a 5-mile land stage length added to each water stage length is simply the trip time given in Exhibit 19 plus 60 minutes (10 miles per hour).

Utilizing the algebraic formulas given above and the times given in Exhibits 18 and 19, the number of vehicles required to lift 5,040 tons of cargo for each vehicle and water stage length was determined. The results are presented tabularly in Exhibits 20 and 22 and graphically in Exhibits 21 and 23. As evidenced in Exhibits 20 and 21 (no land travel), there is a linear relationship between the number of vehicles required and the stage length, ranging from a high coefficient of vehicles to distance in the case of the LARC-5 to a coefficient of nearly one in the case of the GEM IV and the GEM VIII. For the 1-mile water stage length, 66.4 LARC-5 vehicles are required; for the 50-mile water stage length, 614.9 LARC-5 vehicles are required, an almost tenfold increase. For the 1-mile and 50-mile water stage lengths, the number of GEM's IV and VIII required is 51.4 and 82.3, respectively. The rate of increase in the number of LARC-15 vehicles required to service each water stage length is decidedly lower than that for the LARC-5. On an absolute basis, the number of LARC-15 vehicles required to service each water stage length is markedly lower than that for the LARC-5, and generally higher than those for the conceptual vehicles. The BARC manifests, in its turn, a very low rate of increase over the various water stage lengths, similar to the GEM IV and GEM VIII, with an approximate twofold increase in vehicles required from the 1-mile water stage length to the 50-mile water stage length.

With the addition of a 5-mile land stage length (Exhibits 22 and 23), the vehicle population is increased for each water stage length, but the rate of increases and relative positions between vehicle types remain the same. The full significance of Exhibits 20 through 23 can be better appreciated by referring to Exhibit 14, which contains the technical and operating characteristics assigned to each real and conceptual vehicle.

Exhibit 19. Trip Times, Ship to Shore (in minutes).

Vehicle	Water Stage Lengths, Miles									
	1	2	3	4	5	10	20	30	40	50
LARC-5	79.0	92.3	105.6	118.9	132.2	199.0	332.0	465.7	599.0	732.0
LARC-15	187.7	201.0	214.4	227.7	241.0	307.7	441.0	574.4	707.7	841.1
BARC	673.2	690.3	707.5	724.6	741.8	827.5	998.9	1170.3	1341.7	1512.7
Hydroplane I	71.0	75.8	80.6	85.4	90.2	114.2	162.2	210.2	258.2	306.2
Hydroplane II	71.5	74.9	78.4	81.8	85.2	102.4	136.6	170.9	205.2	239.5
Hydroplane III	180.7	185.5	190.3	195.1	199.9	223.9	271.9	319.9	367.9	415.9
Hydroplane IV	179.1	182.5	186.0	189.4	192.8	210.0	244.2	278.5	312.8	347.1
Hydrofoil I	71.2	75.2	79.2	83.2	87.2	107.2	147.2	187.2	227.2	267.2
Hydrofoil II	70.2	73.2	76.2	79.2	82.2	97.2	127.2	157.2	187.2	217.2
Hydrofoil III	127.0	131.0	135.0	139.0	143.0	163.0	203.0	243.0	283.3	323.0
Hydrofoil IV	125.9	128.9	131.9	134.9	137.9	152.9	182.9	212.9	242.9	272.9
GEM I	72.0	75.0	78.0	81.0	84.0	99.0	129.0	159.0	189.0	219.0
GEM II	66.8	68.3	69.8	71.3	72.8	80.3	95.3	110.3	125.3	140.3
GEM III	123.6	126.6	129.6	132.6	135.6	150.6	180.6	210.6	240.6	270.6
GEM IV	122.4	123.9	125.4	126.9	128.4	135.9	150.9	165.9	180.9	195.9
GEM V	72.0	75.0	78.0	81.0	84.0	99.0	129.0	159.0	189.0	219.0
GEM VI	67.8	69.3	70.8	72.3	73.8	81.3	96.3	111.3	126.3	141.3
GEM VII	123.6	126.6	129.6	132.6	135.6	150.6	180.6	210.6	240.6	270.6
GEM VIII	122.4	123.9	125.4	126.9	128.4	135.9	150.9	165.9	180.9	195.9

Exhibit 20. Number of Vehicles Required, Ship to Shore.

Vehicle	Water Stage Lengths, Miles									
	1	2	3	4	5	10	20	30	40	50
LARC-5	66.4	77.5	88.7	99.9	111.0	167.2	278.9	391.2	503.2	614.9
LARC-15	52.6	56.3	59.9	63.8	67.5	86.2	123.5	160.8	198.2	235.5
BARC	47.1	48.3	49.5	50.7	51.9	57.9	69.9	81.9	93.9	105.9
Hydroplane I	59.6	63.7	67.7	71.7	75.8	95.9	136.2	176.6	216.9	257.2
Hydroplane II	60.1	62.9	65.9	68.7	71.6	86.0	114.7	143.6	172.4	201.2
Hydroplane III	50.6	51.9	53.3	54.6	56.0	62.7	76.1	89.6	103.0	116.5
Hydroplane IV	50.1	51.1	52.1	53.0	54.0	58.8	68.4	78.0	87.6	97.2
Hydrofoil I	59.8	63.2	66.5	69.9	73.2	90.0	123.6	157.2	190.8	224.4
Hydrofoil II	59.0	61.5	64.0	66.5	69.0	81.6	106.8	132.0	157.2	182.4
Hydrofoil III	53.3	55.0	56.7	58.4	60.1	68.5	85.3	102.1	118.9	135.7
Hydrofoil IV	52.9	54.1	55.4	56.7	57.9	64.2	76.8	89.4	102.0	114.6
GEM I	60.5	63.0	65.5	68.0	70.6	83.2	108.4	133.6	158.8	184.0
GEM II	56.1	57.4	58.6	59.9	61.2	67.5	80.1	92.7	105.3	117.9
GEM III	51.9	53.2	54.4	55.7	57.0	63.3	75.9	88.5	101.1	113.7
GEM IV	51.4	52.0	52.7	53.3	53.9	57.1	63.4	69.7	76.0	82.3
GEM V	60.5	63.0	65.5	68.0	70.6	83.2	108.4	133.6	158.8	184.0
GEM VI	57.0	58.2	59.5	60.7	62.0	68.3	80.9	93.5	106.1	118.7
GEM VII	51.9	53.2	54.4	55.7	57.0	63.3	75.9	88.5	101.1	113.7
GEM VIII	51.4	52.0	52.7	53.3	53.9	57.1	63.4	69.7	76.0	82.3

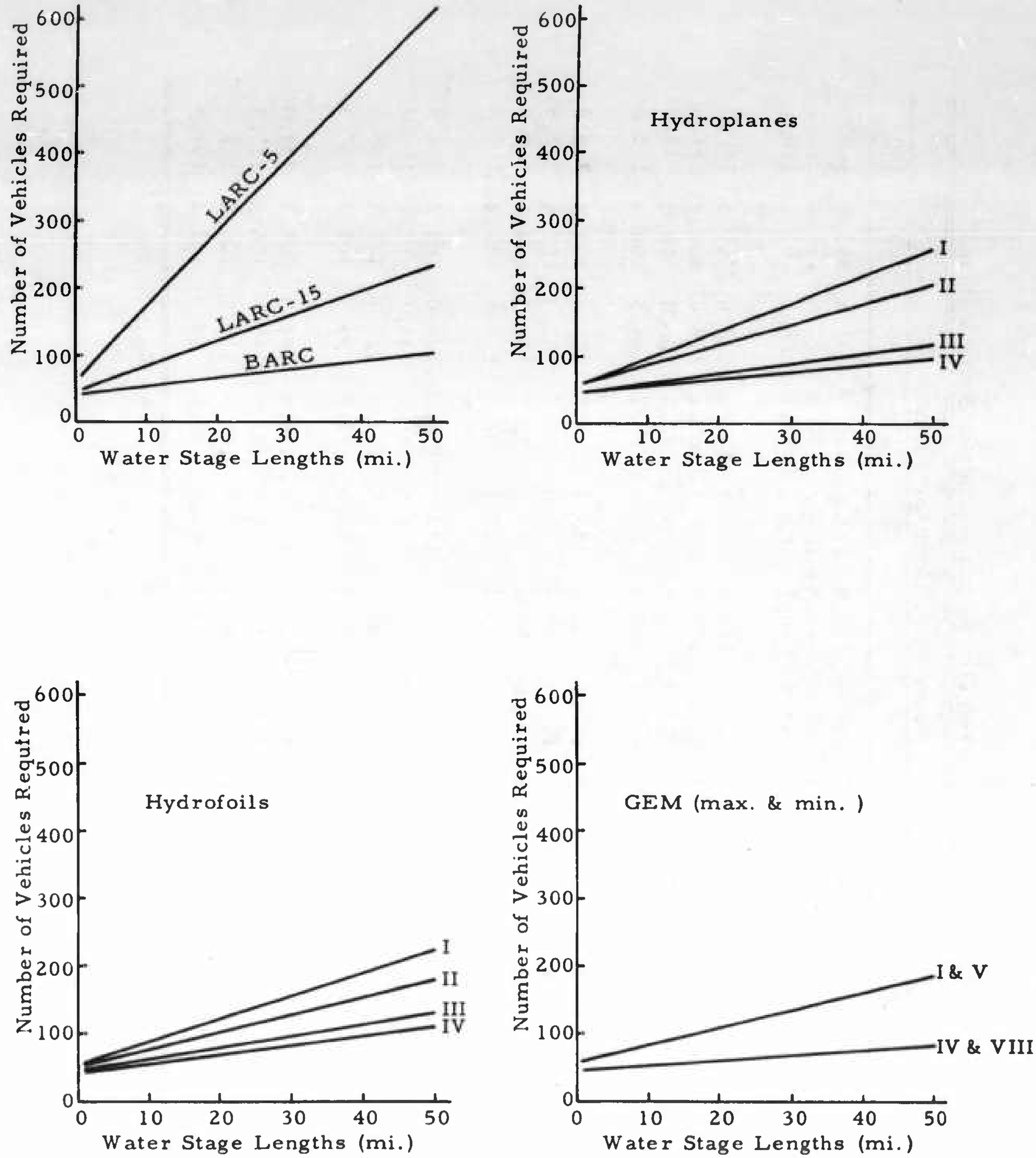

Exhibit 21. Number of Vehicles Required, Ship to Shore.

Exhibit 22. Number of Vehicles Required, Ship to Shore & Inland.

Vehicle	Water Stage Lengths, Miles									
	1	2	3	4	5	10	20	30	40	50
LARC-5	116.8	127.9	139.1	150.3	161.4	217.6	329.3	441.6	553.6	665.3
LARC-15	69.4	73.1	76.8	80.6	84.3	103.0	140.3	177.6	215.0	252.3
BARC	51.3	52.5	53.7	54.9	56.1	62.1	74.1	86.1	98.1	110.1
Hydroplane I	110.0	114.1	118.1	122.1	126.2	146.3	186.6	227.0	267.3	307.6
Hydroplane II	110.5	113.3	116.3	119.1	122.0	136.4	165.1	194.0	222.8	251.6
Hydroplane III	67.[illegible]	68.7	70.1	71.4	72.8	79.5	92.9	106.4	119.8	133.3
Hydroplane IV	66.9	67.9	68.9	69.8	70.8	75.6	85.2	94.8	104.4	114.0
Hydrofoil I	110.2	113.6	116.9	120.3	123.6	140.4	174.0	207.6	241.2	274.8
Hydrofoil II	109.4	111.9	114.4	116.9	119.4	132.0	157.2	182.4	207.6	232.8
Hydrofoil III	78.5	80.2	81.9	83.6	85.3	93.7	110.5	127.3	144.1	160.9
Hydrofoil IV	78.1	79.3	80.6	81.9	83.1	89.4	102.0	114.6	127.2	139.8
GEM I	110.9	113.4	115.9	118.4	121.0	133.6	158.8	184.0	209.2	234.4
GEM II	106.5	107.8	109.0	110.3	111.6	117.9	130.5	143.1	155.7	168.3
GEM III	77.1	78.4	79.6	80.9	82.2	88.5	101.1	113.7	126.3	138.9
GEM IV	76.6	77.2	77.9	78.5	79.1	82.3	88.6	94.9	101.2	107.5
GEM V	110.9	113.4	115.9	118.4	121.0	133.6	158.8	184.0	209.2	234.4
GEM VI	107.4	108.6	109.9	111.1	112.4	118.7	131.3	143.9	156.5	169.1
GEM VII	77.1	78.4	79.6	80.9	82.2	88.5	101.1	113.7	126.3	138.9
GEM VIII	76.6	77.2	77.9	78.5	79.1	82.3	88.6	94.9	101.2	107.5

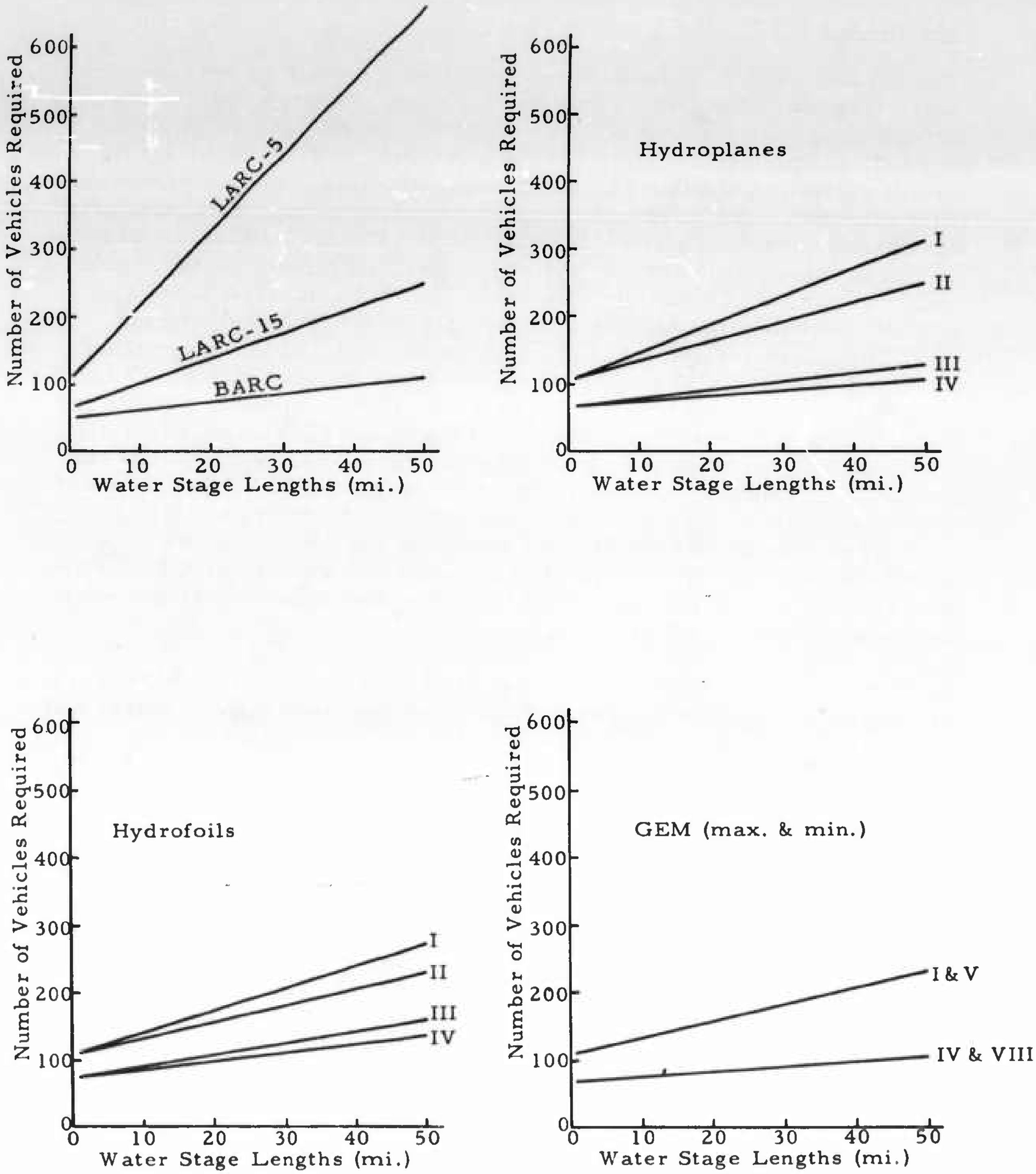

Exhibit 23. Number of Vehicles Required, Ship to Shore & Inland.

VEHICLE INVESTMENT

The number of real and conceptual vehicles required to service each stage length of each type is now known. The next step, preliminary to determining the total vehicle investment required, was to establish a capital cost for each vehicle. This was done, and the resultant figures are presented in Exhibit 24, which shows the first cost for each vehicle, with allowances for research and development, spare parts, and attrition. The first cost given for the LARC-5 is based on the unit cost for a current production run of 230 LARC-5's, completely equipped and ready to run, with Radio Set AN/VRC-19 (VHF radiotelephone) and a $3,500 allowance for MF/HF radiotelephone and radar equipment. The first cost given for the LARC-15 was constructed on the basis of an assumed cost of $2.50 per pound of vehicular weight, including engine weight less crew, fuel, and payload weights. (Component weights for all vehicles are contained in Exhibit 15, page 35.) The pound cost of the LARC-5, based on the specified production run, is $1.50, so that the LARC-15 figure represents an augmentation of $1.00 per pound of vehicular weight. The first cost given for the BARC is simply an average of five prices paid over a period of time for 14 BARC's (numbers 5 through 18), in ready-to-operate condition, with Radio Set AN/VRC-19 and an allowance of $3,500 for additional electronic navigation and communication gear.

The first cost given for Hydroplane I was developed on the basis of an assumed cost of $5 per pound of vehicle weight (less engine weight and crew, fuel, and payload weights) and $35 per engine horsepower (horsepower for all vehicles is contained in Exhibit 14), plus a $3,500 allowance. The $35/horsepower figure was derived from a current, unpublished survey report prepared by the staff of a leading U. S. manufacturer of gas-turbine engines, and represents a forecast of what is expected to obtain in 1964. Regarding the $5/pound figure, it is perhaps high, in view of the $1.50/pound figure for the LARC-5. However, its use seems justified in view of the complexities introduced by wheel retraction arrangements, hull fairing provisions, and other requirements generated by hydroplaning capability. The first cost for Hydroplane II was constructed along the same lines as that for Hydroplane I, that is, $5/pound for vehicle weight, $35/horsepower, and a $3,500 allowance. First costs for Hydroplanes III and IV, each of which has a 15-ton payload capability, was constructed on the basis of $6/pound for vehicle weight (less engine, crew, fuel, and payload weights as given in Exhibit 14), $35/horsepower, and an allowance of $3,500 for communication and navigation equipment.

Exhibit 24. Schedule of Capital Costs.

Vehicle	Research and Development $	First Costs $	Spare Parts $	Attrition $	Total $
LARC-5	1,300	40,900	6,100	4,100	52,400
LARC-15	3,400	87,900	13,200	8,800	113,300
BARC	*	298,200	44,700	29,800	372,700
Hydroplane I	3,300	132,900	22,600	13,300	172,100
Hydroplane II	4,000	179,500	30,500	18,000	232,000
Hydroplane III	7,500	336,300	57,200	33,600	434,600
Hydroplane IV	8,800	418,400	71,100	41,800	540,100
Hydrofoil I	5,500	246,000	46,700	26,600	322,800
Hydrofoil II	6,400	262,600	49,900	26,300	345,200
Hydrofoil III	9,300	576,400	109,500	57,600	752,800
Hydrofoil IV	10,700	602,100	114,400	60,200	787,400
GEM I	12,800	361,000	54,200	36,100	464,100
GEM II	17,800	545,500	81,800	54,600	699,700
GEM III	21,600	444,100	66,600	44,400	576,700
GEM IV	27,900	720,700	108,100	72,100	928,800
GEM V	12,800	535,900	80,400	53,600	682,700
GEM VI	17,700	351,900	52,800	35,200	457,600
GEM VII	21,600	773,100	116,000	77,300	988,000
GEM VIII	27,900	509,500	76,400	51,000	664,800

*Written off.

First costs for Hydrofoils I and II were developed utilizing $10/pound for vehicle weight (less engine, crew, fuel, and payload weights), $35/engine horsepower, and an addition of $3,500. First costs for Hydrofoils III and IV were similarly arrived at, except that a cost per pound of $12 was used in lieu of $10. The pound cost rates ($10 for Hydrofoils I and II and $12 for Hydrofoils III and IV) were established on the basis of cost information provided informally by technical personnel of two U. S. firms having experience in hydrofoil design and construction and on the basis of the calculated pound costs of the Supramar PT 20 and PT 50 hydrofoil boats (see Exhibit 7, on pages 13 and 14, for technical and other details with respect to these two hydrofoil boats). The provided cost information applied to respective company proposals for hydrofoil amphibians with technical and operational features somewhat akin to those for Hydrofoils I and II. One of the two company sources estimated that the unit production cost (100 units or more) would run between $90,000 and $130,000, or $4.50 per pound of vehicle weight (empty) less engine weight and cost at the latter price. The second company source estimated that the unit production cost of their particular hydrofoil amphibian design would run about $250,000, or $9.00 per pound of vehicle weight (empty) less engine weight and cost. The pound costs of the Supramar PT 20 and PT 50 boats were found to be about $4.50 and $6.50, respectively, less engine weights and costs. It would appear that the cost estimate provided by the first company was somewhat optimistic, considering further that the Supramar boat costs are based on construction under European economic conditions and the design requirements are far less simple than those for amphibians with retractable foils and wheels and a complicated power transmission system. The utilized figures of $10 and $12 are not unduly high. Quite possibly, they may be too low. In reality, it should be noted, little or no actual direct cost data exist.

First costs for all GEM vehicles were constructed on the basis of $18 per pound of empty weight of vehicle less engine weight, $35 per engine horsepower, and an allowance of $3,500. The $18 cost figure was derived from a cost analysis of some 50 aircraft ranging up to 10,000 pounds in weight, in which $18 was found to be the average cost per pound of aircraft (empty) less engine weight and cost.[22] As reported, the current cost of U. S. Naval aircraft is $110 per pound, including engine.[23] The utilization of the cost figure of $18 in arriving

[22] Aviation Week, Vol. 72, No. 10, 7 March 1960, p. 179.

[23] Rear Adm. Paul D. Stroop, USN, "Making Defense Dollars Do More", Aerospace Management, Vol. 4, No. 8, August 1961, p. 60.

at the first costs for the GEM vehicles, it should be explained here, was based on the assumption that aircraft and GEM vehicles are analogous in many design respects and that the latter type of air vehicle is relatively unsophisticated compared to larger and faster aircraft than those included in the analysis of the 50 aircraft. Design requirements imposed by safety considerations can be expected to be less stringent, for one thing. On the other hand, sophistication or complexity may be introduced in the form of multiple fan and power plant arrangements, ducting, and other provisions in GEM design, particularly for the larger GEM vehicles.

In developing first costs, no attempt was made to analyze cost differences arising from differences in quantity of output.[24]

The research and development costs given in Exhibit 24 are the actual costs incurred to date for the LARC-5 and the LARC-15, which approximate $1.7 million each, distributed over roughly twice the number of vehicles cited in the last column appearing in Exhibit 22. In the case of the BARC, which has been operational for some time, actual research and development cost data were found to be unavailable at this late date, so costs were simply written off for the BARC. For the conceptual vehicles, research and development costs were estimated, as follows: $2.0 million for each hydroplane, $3.0 million for each hydrofoil vehicle, and $6.0 million for each GEM vehicle, distributed similarly to the research and development costs for the LARC-5 and the LARC-15. The estimates were developed on the basis of consultation with cognizant individuals and the recorded experience to date.

Spare parts were taken as a percentage of first costs: 15 percent for the LARC's and the BARC, 17 percent for the hydroplane vehicles, 19 percent for the hydrofoil vehicles, and 15 percent for the GEM vehicles. These percentages are considered to be reasonable and representative of the differences in vehicular complexities. Attrition is assumed at 10 percent of first cost. This is a very nominal rate, and is more symbolic than realistic. Essentially, it is an allowance for accidents and other contingencies. The last column in Exhibit 24 totals the component costs making up the capital costs for each real and conceptual vehicle under examination.

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[24] See Gordon B. Carson, Editor, Production Handbook, 2nd Edition, The Ronald Press Company, New York, New York, 1958, pp. 2.25-2.32, on economic quantities of production and methodology of determination.

The total vehicle investment requirement for each water stage length and for each water stage length with a 5-mile land stage length added is presented tabularly in Exhibits 25 and 27 and graphically in Exhibits 26 and 28. The tables were constructed by simple multiplication utilizing the data contained in Exhibits 20 and 22, listing the number of vehicles required to service each water stage length, and in Exhibit 24, providing the capital cost for each vehicle. As shown in Exhibit 20, the vehicle investment requirement varies from a low of $3.5 million and a high of $51.3 million for the 1-mile water stage length to a low of $26.7 million and a high of $125.6 million for the 50-mile water stage length. In Exhibit 26, it is clearly shown that the LARC-5 and the LARC-15 command a superior position out to the 50-mile limit in the matter of capital investment. At the 15-mile limit, the LARC-15 takes over from the LARC-5 as the lowest investment cost vehicle, including both real and conceptual vehicles. The BARC runs behind Hydroplanes I and II to about the 30- and 18-mile limits, respectively, thereafter assuming the third best place next after the LARC's in the matter of capital costs. As a group, the hydroplanes rank next best after the real vehicles, followed by hydrofoils and GEM's in mixed order.

With the addition of a 5-mile land stage length, the vehicle investment requirement (Exhibit 27) rises from a low of $6.1 million and a high of $76.2 million for the 1-mile water stage length to a low of $28.6 million and a high of $160.0 million for the 50-mile water stage length. As shown graphically in Exhibit 28, the addition of a land stage length improves the relative cost position of the real vehicles, particularly that of the BARC. It assumes a clear cost advantage over the conceptual vehicles except for the first 2 miles, for which Hydroplane I manifests lower capital costs. At about the 12-mile stage limit, the LARC-15 supplants the LARC-5 as the lowest investment vehicle. The hydroplanes continue to hold the second best position in the matter of vehicle investment. Among both the hydroplanes and the balance of the conceptual vehicles, changes in rank occur.

TON-MILE COSTS

To determine ton-mile costs, it is first necessary to establish hourly operating costs for each vehicle. Such costs as they pertain to direct costs are presented in Exhibit 29. Indirect, or constant, costs are not considered in this analysis. The first column gives the hourly crew costs for each vehicle. They were developed utilizing Exhibit 14, which shows the number of enlisted personnel assigned to each vehicle, with respective grades. The assigned complement was, in turn, selected on

Exhibit 25. Vehicle Investment, Ship to Shore (in millions of dollars).

Vehicle	Water Stage Lengths, Miles									
	1	2	3	4	5	10	20	30	40	50
LARC-5	3.5	4.1	4.6	5.2	5.8	8.8	14.6	20.5	26.4	32.2
LARC-15	6.0	6.4	6.8	7.2	7.6	9.8	14.0	18.2	22.5	26.7
BARC	17.6	18.0	18.4	18.9	19.3	21.6	26.1	30.5	35.0	39.5
Hydroplane I	10.3	11.0	11.7	12.3	13.0	16.5	23.4	30.4	37.3	44.3
Hydroplane II	13.9	14.6	15.3	15.9	16.6	20.0	26.6	33.3	40.0	46.7
Hydroplane III	22.0	22.6	23.2	23.7	24.3	27.2	33.1	38.9	44.8	50.6
Hydroplane IV	27.1	27.6	28.1	28.6	29.2	31.8	36.9	42.0	47.3	52.6
Hydrofoil I	19.3	20.4	21.5	22.6	23.6	29.1	40.0	50.7	61.6	72.4
Hydrofoil II	20.4	21.2	22.1	23.0	23.8	28.2	36.9	45.6	54.3	63.0
Hydrofoil III	40.1	41.4	42.7	44.0	45.2	51.6	64.2	76.9	89.5	102.2
Hydrofoil IV	41.7	42.6	43.6	44.6	45.6	50.6	60.5	70.4	80.3	90.2
GEM I	28.1	29.2	30.4	31.6	32.8	38.6	50.3	62.0	73.7	85.4
GEM II	39.3	40.2	41.0	41.9	42.8	47.2	56.0	64.9	73.7	82.5
GEM III	29.9	30.7	31.4	32.1	32.9	36.5	43.8	51.0	58.3	65.6
GEM IV	47.7	48.3	48.9	49.5	50.1	53.0	58.9	64.7	70.6	76.4
GEM V	41.3	43.0	44.7	46.4	48.2	56.8	74.0	91.2	108.4	125.6
GEM VI	26.1	26.6	27.2	27.8	28.4	31.3	37.0	42.8	48.6	54.3
GEM VII	51.3	52.6	53.7	55.0	56.3	62.5	75.0	87.4	100.0	112.3
GEM VIII	34.2	34.6	35.0	35.4	35.8	38.0	42.0	46.3	50.5	54.7

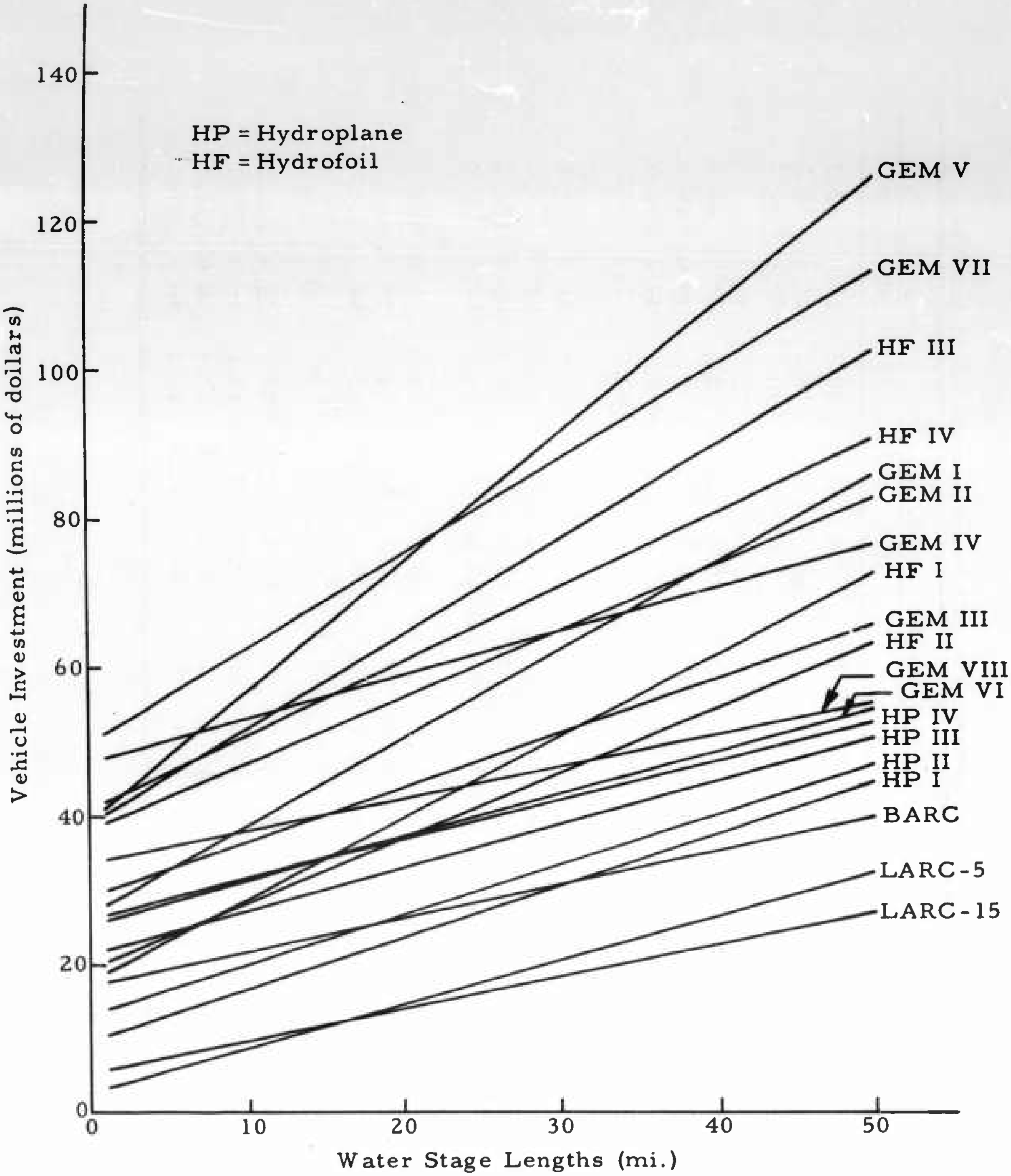

Exhibit 26. Vehicle Investment, Ship to Shore.

Exhibit 27. Vehicle Investment, Ship to Shore & Inland (in millions of dollars).

Vehicle	Water Stage Lengths, Miles									
	1	2	3	4	5	10	20	30	40	50
LARC-5	6.1	6.7	7.3	7.9	8.5	11.4	17.3	23.1	29.0	34.9
LARC-15	7.9	8.3	8.7	9.1	9.6	11.7	15.9	20.1	24.4	28.6
BARC	19.1	19.6	20.0	20.5	20.9	23.1	27.6	32.1	36.6	41.0
Hydroplane I	18.9	19.6	20.3	21.0	21.7	25.2	32.1	39.1	46.0	52.9
Hydroplane II	25.6	26.3	27.0	27.6	28.3	31.6	38.3	45.0	51.7	58.4
Hydroplane III	29.3	29.9	30.5	31.0	31.6	34.6	40.4	46.2	52.1	57.9
Hydroplane IV	36.1	36.7	37.2	37.7	38.2	40.8	46.0	51.2	56.4	61.6
Hydrofoil I	35.6	36.7	37.7	38.8	40.0	45.3	56.2	67.0	77.9	88.7
Hydrofoil II	37.8	38.6	39.5	40.4	41.2	45.6	54.3	63.0	71.7	80.4
Hydrofoil III	59.1	60.4	61.7	62.9	64.2	70.5	83.2	95.8	108.5	121.1
Hydrofoil IV	61.5	62.4	63.5	64.5	65.4	70.4	80.4	90.2	100.2	110.1
GEM I	51.5	52.6	53.8	54.9	56.2	62.0	73.7	85.4	97.1	108.8
GEM II	74.5	75.4	76.3	77.2	78.1	82.5	91.3	100.1	108.9	117.8
GEM III	44.5	45.2	45.9	46.7	47.4	51.0	58.3	65.6	72.8	80.1
GEM IV	71.1	71.7	72.4	72.9	73.5	76.4	82.3	88.1	94.0	99.8
GEM V	75.7	77.4	79.1	80.8	82.6	91.2	108.4	125.6	142.8	160.0
GEM VI	49.1	49.7	50.3	50.9	51.4	54.3	60.1	65.8	71.6	77.4
GEM VII	76.2	77.5	78.6	79.9	81.2	87.4	100.0	112.3	124.8	137.2
GEM VIII	50.9	51.3	51.8	52.2	52.6	54.7	58.9	63.1	67.3	71.5

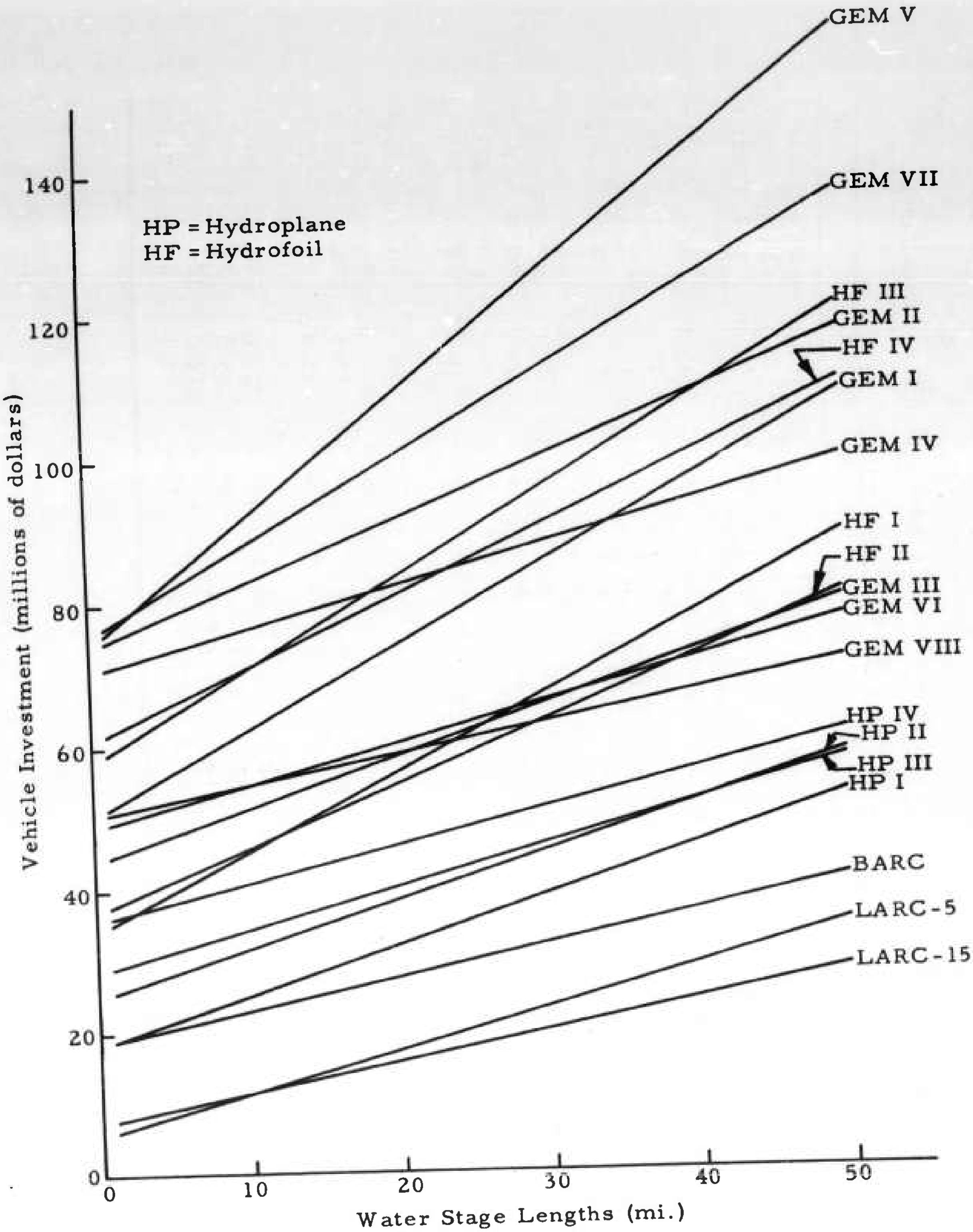

Exhibit 28. Vehicle Investment, Ship to Shore & Inland.

Exhibit 29. Schedule of Direct Operating Costs (hourly).

Vehicle	Crew $	Fuel $	Maintenance $	Total $
LARC-5	2.80	3.02	3.27	9.09
LARC-15	2.80	6.04	7.03	15.87
BARC	7.21	3.46	17.89	28.56
Hydroplane I	3.43	5.89	5.85	15.17
Hydroplane II	3.43	11.78	7.90	23.11
Hydroplane III	4.06	15.71	14.80	34.57
Hydroplane IV	4.06	23.56	18.41	46.03
Hydrofoil I	3.43	4.32	12.30	20.05
Hydrofoil II	3.43	7.07	13.13	23.63
Hydrofoil III	4.06	8.24	28.82	41.12
Hydrofoil IV	4.06	13.74	30.11	47.91
GEM I	3.43	18.85	14.44	36.72
GEM II	3.43	76.17	21.82	101.42
GEM III	4.06	31.41	17.76	53.23
GEM IV	4.41	78.53	28.83	111.77
GEM V	3.43	45.55	21.44	70.42
GEM VI	3.71	41.62	14.08	59.41
GEM VII	4.06	84.03	30.92	119.01
GEM VIII	4.41	40.84	20.38	65.63

the basis of the relevant operational responsibility and vehicle investment. Multiplying each grade assignment by the respective hourly grade salary, as reported in AR 35-247,[25] and totalling for each vehicle, provides the total hourly crew costs, as shown in Exhibit 29.

The hourly fuel costs shown in Exhibit 29 were calculated utilizing the hourly fuel consumption rates given in Exhibit 2 (page 4) for the real vehicles, a consumption rate of .6/pound/horsepower/hour for the conceptual vehicles (see Exhibit 14 for horsepower ratings), and the following fuel prices: $0.151 per gallon for gasoline, $0.091 per gallon for diesel fuel, and $0.089 per gallon for kerosene.[26] Conversion of fuel prices from gallons to pounds was accomplished on the

[25] AR 35-247, Finance & Fiscal - Military Compensation Rate Tables, Headquarters, Department of the Army, Washington, D. C., 3 July 1958, p. 5.

[26] Petroleum Price Bulletin, Quartermaster Petroleum Center, U. S. Army, Washington, D. C., 1 July 1960.

basis of the following rates: 6.2 pounds per gallon for gasoline, 6.8 pounds per gallon for kerosene, and 7.2 pounds per gallon for diesel oil.[27] All fuel costs and consumption rates were calculated at full-throttle operation.

Considered, but not included, in the cost schedule were costs relating to the use of consumption of crankcase oil, transmission oil, hydraulic oil, differential oil, and other oils and lubricants. At the price of $.46 per gallon (SAE, MIL-L-21044),[28] with an oil change every 100 hours in the case of the LARC-5 (11-quart capacity) and LARC-15 (22-quart capacity) and every 150 hours for the BARC (80-quart capacity), crankcase oil costs came to about 1-2 cents, 3 cents, and 6 cents per hour of operation for the three vehicles, respectively.[29] Engine oil requirements for gas-turbine engines—equipping the conceptual vehicles—are noticeably small and negligible, generally speaking.[30] On the other hand, oil requirements for other applications and for lubricants could run high for the hydroplanes and for the hydrofoils in particular. The latter, characterized by retractable wheels and foils, land-water power transmission systems, and other design complexities, can be expected to be heavy users of oils and lubricants.

Maintenance costs were estimated as a percentage of first costs—40 percent for the LARC-5 and LARC-15, 30 percent for the BARC, 22 percent for the hydroplanes, 25 percent for the hydrofoils, and 20 percent for the GEM's—spread over a vehicle service life of 5,000 hours of operation. The rationale for assigning maintenance costs in this way follows.

In general, actual maintenance costs are not known, and very little analogous or transfer experience was found to be available. This is true for both the real and the conceptual vehicles. The LARC's are

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[27] Theodore Baumeister, Editor, Mechanical Engineers' Handbook, 6th Edition, McGraw-Hill Book Company, New York, New York, 1958, Sec. 7, p. 21.

[28] Petroleum Price Bulletin, op. cit.

[29] Cost of oils and lubricants for the LARC-5-1X for 894 hours of endurance operation averaged $.46 per hour. See Endurance Test Report, LARC 5 Prototype No. 1, Report No. 1, Contract DA 44-177-TC-479, Borg-Warner Corp., Ingersoll Kalamazoo Division, Kalamazoo, Michigan, May 1960, Sec. 7, p. 88.

[30] Paul H. Wilkinson, Aircraft Engines of the World, 1959/60, Paul H. Wilkinson (publisher), Washington, D. C., 1959, 320 pp. (Reports engine oil consumption rates for a number of gas-turbine engines.)

in existence, to be sure, and a certain measure of maintenance information is available in engineering and test reports. They are new, however, and insufficient time has elapsed to develop firm maintenance cost data on the basis of long-term operational experience. In the case of the BARC, excellent maintenance data were located,[31] but they were found to be in a form which could not be used. The data did serve to indicate, however, that the hourly maintenance costs allowed in Exhibit 29, and the spare parts allowance given for the BARC in Exhibit 24, were not unreasonable, and indicatively so, for the LARC-5 and the LARC-15.

The hydroplanes differ essentially from the LARC's in water-planing and wheel-retraction (with hull fairing design provisions) capabilities and in the utilization of gas-turbine power. To plane effectively the hull must be kept clean and free of major surface imperfections (in the same way as the surface areas of aircraft), which will add concomitantly to maintenance and repair costs. Wheel retraction, comprising wheels, wheel support and folding members, wheel house closures, hydraulic cylinders and actuators, etc., adds to mechanical complexity and to maintenance costs. The utilization of gas-turbine power, on the other hand, can be expected to reduce engine maintenance costs sharply, as much as 300 percent and more over maintenance costs for gasoline engines and diesel engines.[32]

Considering the present trend of overhaul intervals for gas-turbine engines, 5,000 hours running without overhaul is entirely conceivable within the next few years. Some currently available gas-turbine engines already exceed this number of hours between overhaul.[33] The LARC gasoline engines, for their part, can be expected to require one major overhaul during a period of 5,000 hours of work. Diesel engines should be able to run 5,000 hours without major overhaul, but with

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[31] BARC Information Letter, December 1960 (U), BARC Information Letter, January 1961 (U), and BARC Information Letter, March 1961 (U), op. cit. (see footnote 20 for full reference); and Conference Information on Operation and Maintenance Costs, 554th Transportation Platoon (BARC), 14th Transportation Battalion (Terminal), Fort Story, Virginia, undated.

[32] "Gas Turbine Experience - The Record", Gas Turbine, Vol. 1, No. 1, January-February 1960, pp. 22-25; and 1958 Gas-Turbine Progress Report, The American Society of Mechanical Engineers, New York, New York, pp. 97-123.

[33] 1958 Gas-Turbine Progress Report, op. cit., p. 105.

more periodic and special maintenance than that required for gas-turbine engines. Since all the conceptual vehicles—hydroplane,, hydrofoil, and GEM—have been given gas-turbine engines, the connected maintenance advantages obtain for all.

The hydrofoils, in their turn, differ essentially from the hydroplanes in having retractable foils and extendable-propeller-drive and electronic-stability systems, as envisioned, all in support of foil operations and all adding importantly to the cost of maintenance. The foils are susceptible to a certain amount of damage resulting from collision with floating and stationary objects. The foils as well as the hull must be kept very clean in order to reduce drag to a minimum and to insure take-off capability. As related in Part Two, foil maintenance for the Supramar PT 20 hydrofoil boat in commercial operations consumes about 25 percent of the total maintenance time expended, or about 8 hours per 100 hours of running time. The PT 20, it should be noted, is equipped with nonretractable foils. In tropical waters, foil and hull maintenance is increased because of the more rapid growth of marine life.[34] The utilization of retractable foils, as envisioned for the conceptual hydrofoils, does reduce the maintenance requirement, on the other hand. However, this advantage is offset by maintenance requirements relating to the retraction mechanisms for foils and the propeller-drive system. Finally, if the foil system is of the fully submerged type (partially or wholly so), proper foil attitude must be maintained by mechanical, electrical, or some other means with the requisite maintenance requirement. Viewed generally, the hydrofoil amphibian is a complicated piece of machinery as much as it is a transport vehicle, with the concomitant effects on maintenance.

The GEM vehicles, in comparison to the hydroplanes and hydrofoils, are much simpler in design, as envisioned, consisting essentially of a hull or planform and propulsion system, without the technical complexities of retractable wheels, foils, and water-land drive systems of the latter. The GEM vehicles may be considered akin to aircraft in

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[34] In addition to this problem, operation in tropical waters is affected by the lower air density as against that in more temperate zones, reducing power output by at least 10 percent, according to von Schertel. Reference Hanns von Schertel, Hydrofoil Boats as a New Means of Transportation (Revised, May 1959), a paper presented to the New York Metropolitan Section of the Society of Naval Architects and Marine Engineers, 30 October 1958, p. 20. See also Modification and Testing of a World War II DUKW, op. cit., Sec. 1, p. 15.

design, but at a lower level of sophistication in safety requirements, in electronic equipment, and in other respects. As shown in Exhibit 29, the total maintenance costs (labor only) allowed for the GEM vehicles varies between a low of $14.08 for GEM VI to a high of $30.92 for GEM VII.

In contrast, the hourly maintenance cost per flying hour runs between $4.78 and $11.46 for a group of fixed-wing Army aircraft (namely, L-19A, L-19D, L-20A, L123D, L-26, and U-1A Otter) and between $5.86 and $59.27 for a group of rotary-wing Army aircraft (namely, H-13G, H-13H, H-23C, H-23D, H-19D, H-21C, H-34A, and H-37A).[35] These costs include first and second echelon (organizational) maintenance, computed on the basis of an average hourly military wage of $1.66 (CONUS average); third echelon (field) maintenance, computed at an average hourly wage of $1.66 for military and $1.95 for civilian labor; and fourth echelon (heavy field) maintenance, computed at the actual labor cost. Not included are fifth echelon (overhaul) maintenance costs. For both types of aircraft, electric and power plant (all reciprocating engines) maintenance ranks high in time and money costs. Viewed generally, the maintenance costs allowed for the GEM vehicles do not seem too unrealistic, considering additionally the present technological progress.

Exhibit 30 presents the total hourly costs for the real and conceptual vehicles, comprised of capital costs as given in Exhibit 24 distributed over a vehicle service life of 5,000 hours and direct operating costs as given in Exhibit 29. Maintenance costs, it may be noted here, are treated as direct costs, some of which could conceivably be considered as indirect, that is, incurred whether the equipment is operated or not. It can be seen that total hourly costs vary from a low of $19.57 for the LARC-5 to a high of $316.61 for the GEM VII. Categorically ranked, the lowest total hourly costs are represented by the displacement-hull vehicles, followed by the hydroplanes as a group, then hydrofoils, and lastly the GEM vehicles. Individually ranked, the order is LARC-5, LARC-15, Hydroplane I, Hydroplane II, Hydrofoil I, Hydrofoil II, BARC, Hydroplane III, GEM I, GEM VI, Hydroplane IV, and so on.

Referring to Exhibit 14, which gives the technical and operational characteristics for each vehicle, and Exhibit 30, showing the total hourly cost of operating each vehicle, it can be readily seen, for

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[35] Maintenance and Operating Costs of Army Aircraft, U. S. Army Transportation Materiel Command, St. Louis, Missouri, February 1961, pp. 1-85.

Exhibit 30. Total Hourly Costs.

Vehicle	Capital Costs $	Direct Operating Costs $	Total Hourly Costs $
LARC-5	10.48	9.09	19.57
LARC-15	22.66	15.87	38.53
BARC	74.54	28.56	103.10
Hydroplane I	34.42	15.17	49.59
Hydroplane II	46.40	23.11	69.51
Hydroplane III	86.92	34.57	121.49
Hydroplane IV	108.02	46.03	154.05
Hydrofoil I	64.56	20.05	84.61
Hydrofoil II	69.04	23.63	92.67
Hydrofoil III	150.56	41.12	191.68
Hydrofoil IV	157.48	47.91	205.39
GEM I	92.82	36.72	129.54
GEM II	139.94	101.42	241.36
GEM III	115.34	53.23	168.57
GEM IV	185.76	111.77	297.53
GEM V	136.54	70.42	206.96
GEM VI	91.52	59.41	150.93
GEM VII	197.60	119.01	316.61
GEM VIII	132.96	65.63	198.59

example, that the total hourly cost of operating at an altitude of 3.0 feet in the case of the GEM I and 5.0 feet in the case of the GEM V (both with a 5-ton payload capability and maximum speed of 40 miles per hour) is the difference between the respective total hourly operating costs of $129.54 and $206.96, or $77.42. Other significant observations relative to costs and cost differences can be made by consulting and utilizing the pertinent exhibits, as in the matter here.

At this point, we have identified and prorated the direct and capital costs over the assigned operational life of the vehicles under examination. We are now ready to compute ton-mile costs. For this purpose, the following algebraic formula was developed and utilized:

$$C_{tm} = \frac{C_s T_m + C_1 T_t}{60PD}$$

where

C_{tm} = cost per ton-mile, \$

C_s = cost per hour for fuel, maintenance, and capital, \$/hour

T_m = time vehicle is in motion, minutes

C_l = cost per hour for labor, \$/hour

T_t = total trip time, minutes

P = payload of vehicle, tons

D = distance cargo is moved, or stage length, miles.

Values for C_s and C_l are obtained directly from Exhibits 29 and 30. Those for T_t are taken directly from Exhibit 19. The values for T_m are based simply on T_t, as shown for the various vehicles and stages in Exhibit 19, less the pertinent loading and unloading times, as presented in Exhibit 18. The computation of ton-mile costs with a 5-mile land stage length added requires simply the addition of 60 minutes to T_t and to T_m and the augmentation of D by 5 miles. Vehicle payloads, P, are available from Exhibit 14.

As evidenced from an inspection of the above formula, fuel, maintenance, and capital costs are charged against the operational life of the vehicles only while they are in motion. Labor costs, on the other hand, are charged against the entire trip time, including times in motion and times not in motion. This method of cost allocation represents a somewhat unreal situation. It implies, among other things, that the engines are closed down, or inoperative, while the vehicle is standing. In reality, vehicles can be expected to keep their engines on, or idling, for precautionary and other cogent reasons, particularly while in the water. Fuel consumption and concomitantly costs will be lower under the circumstances than the hourly fuel costs given in Exhibit 29, which are based on full-throttle operation. In idle condition and at reduced speeds, aside from differences in engine size and output, fuel consumption will be inherently low for the real vehicles, which are equipped with gasoline and diesel engines, and relatively high for the gas-turbine-equipped conceptual vehicles. Pertinently, gas-turbine engines can be started up and closed down quickly and at will, while gasoline and diesel engines are not so capable.

Concerning maintenance costs, while a vehicle is stopped and the engines are shut off, a certain amount of wear and tear on equipment is incurred and upkeep requirements are generated, particularly in a water environment. Capital costs, for their part, do not necessarily stop with the stoppage of equipment. The cost allocation system, then, is admittedly deficient. Nevertheless, it serves to show in an acceptable way, as will be seen, the relative ton-mile cost positions of the different vehicles under examination.

Exhibits 31 and 33 tabularly present ton-mile costs for each vehicle and water stage length, with the latter exhibit including the addition of a 5-mile land stage length to each water stage length. Exhibits 32 and 34 graphically present, in their turn, ton-mile costs averaged for each kind of vehicle, that is, displacement, hydroplane, hydrofoil, and ground effect. The latter exhibit gives ton-mile costs with land movement.

As shown in Exhibit 31, ton-mile costs for ship-to-shore movement, computed by utilizing the methodology outlined above, vary from a low of $1.88 (LARC-15) and a high of $14.62 (GEM V) for the 1-mile water stage length to a low of $.54 (BARC) and a high of $2.32 (GEM V) for the 50-mile water stage length. From a cursory examination of the tabular data presented, it can be readily observed that ton-mile costs for the LARC-15 and the BARC are consistently less than those for any of the conceptual vehicles through the various stage lengths.

Ton-mile costs for the LARC-5 are less than those for the conceptual vehicles through the 5-mile water stage length, thereafter climbing above those of some of the conceptual vehicles, principally, hydroplanes. With respect to ranking, the LARC-15 provides the lowest ton-mile costs, followed by the LARC-5 and the BARC in that order for the 1-mile water stage length. At the 2-mile water stage length, the LARC-5 drops to third place and the BARC moves up to second place. From the 10-mile water stage length to the 20-mile water stage length, a second change in ranking occurs among the real vehicles, between the BARC and the LARC-15, placing the former in first place and the latter in second position. At the 50-mile water stage length, ranking finds the BARC in first place, the LARC-15 in second place, and the LARC-5 in eighth place, with intermediate positions being held by Hydroplanes I through IV and GEM VIII.

Turning briefly to Exhibit 32, which averages ship-to-shore ton-mile costs for each type of vehicle, it can be seen that the cost curves presented drop precipitously over the first few miles, particularly for the conceptual vehicle groups, bottom out between the 5-mile and 20-mile water stage length, and then assume an almost straight-line function, tilted downward slightly to the limit of the 50-mile water stage length. It may be further observed that the averaging curves behave rather similarly, acting in unison, and tend to close toward each other at the high end of the chart in two distinct associations. Finally, it is further demonstrated that the real vehicles have a definite advantage in the matter of ton-mile costs considered as a group,

Exhibit 31. Ton-Mile Costs, Ship to Shore (dollars).

Vehicle	Water Stage Lengths, Miles									
	1	2	3	4	5	10	20	30	40	50
LARC-5	2.27	1.57	1.33	1.22	1.15	1.01	.94	.92	.90	.90
LARC-15	1.88	1.23	1.01	.90	.83	.70	.64	.61	.60	.60
BARC	2.77	1.63	1.25	1.06	.95	.72	.60	.57	.55	.54
Hydroplane I	3.79	2.29	1.79	1.54	1.39	1.09	.94	.89	.87	.85
Hydroplane II	5.19	2.99	2.26	1.89	1.67	1.23	1.01	.94	.90	.88
Hydroplane III	4.17	2.41	1.82	1.53	1.35	1.00	.82	.77	.74	.72
Hydroplane IV	4.82	2.70	2.00	1.65	1.43	1.01	.80	.73	.69	.67
Hydrofoil I	6.10	3.61	2.79	2.37	2.12	1.63	1.38	1.29	1.25	1.23
Hydrofoil II	6.32	3.62	2.72	2.27	2.00	1.47	1.20	1.11	1.06	1.03
Hydrofoil III	8.26	4.77	3.61	3.02	2.67	1.98	1.63	1.51	1.45	1.42
Hydrofoil IV	8.42	4.73	3.49	2.88	2.51	1.77	1.40	1.27	1.21	1.17
GEM I	9.37	5.33	3.99	3.31	2.91	2.10	1.70	1.56	1.50	1.46
GEM II	12.77	6.99	5.06	4.10	3.52	2.36	1.78	1.59	1.50	1.44
GEM III	6.39	3.62	2.69	2.23	1.95	1.40	1.12	1.03	.98	.95
GEM IV	10.21	5.48	3.90	3.11	2.64	1.69	1.22	1.06	.98	.93
GEM V	14.62	8.34	6.25	5.20	4.58	3.32	2.70	2.49	2.38	2.32
GEM VI	8.76	4.76	3.42	2.75	2.35	1.55	1.15	1.02	.95	.91
GEM VII	11.39	6.49	4.85	4.04	3.55	2.56	2.07	1.91	1.83	1.78
GEM VIII	7.07	3.78	2.68	2.13	1.81	1.15	.83	.72	.66	.63

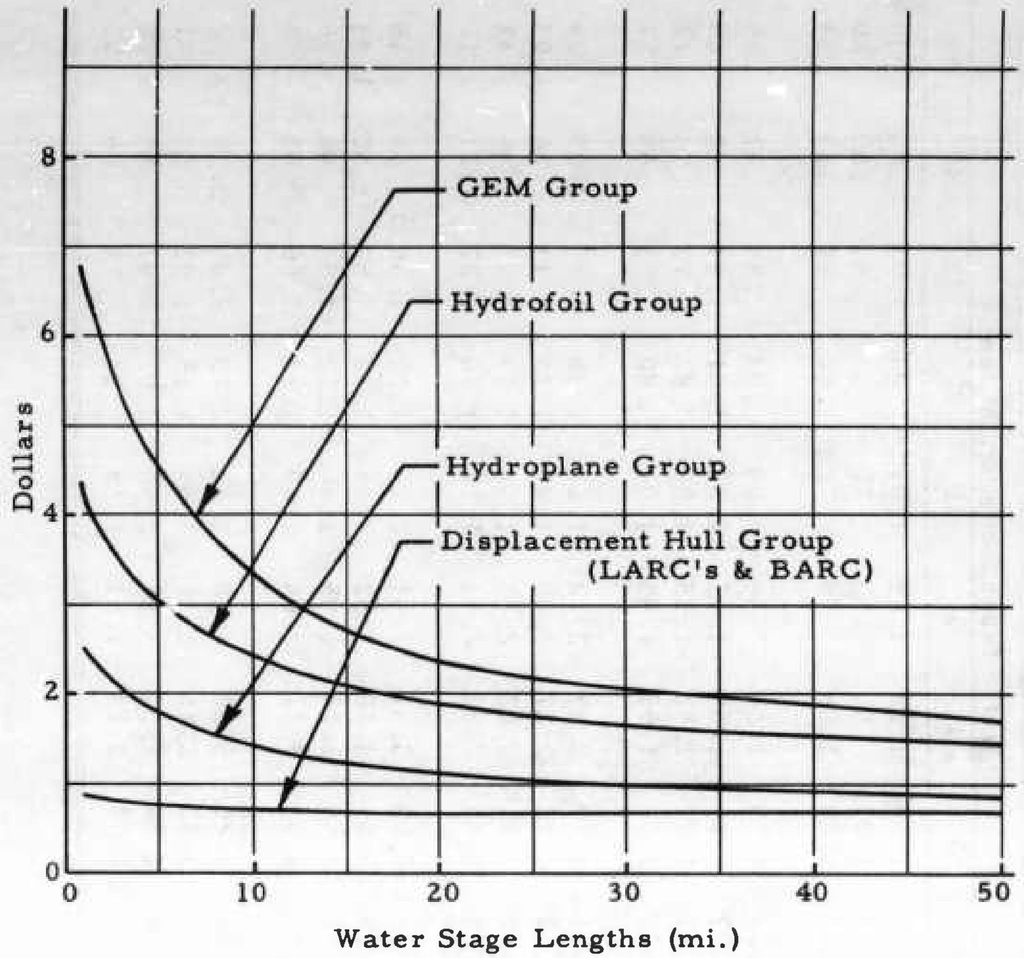

Exhibit 32. Ton-Mile Costs, Ship to Shore.

Exhibit 33. Ton-Mile Costs, Ship to Shore & Inland (dollars).

Vehicle	Water Stage Lengths, Miles									
	1	2	3	4	5	10	20	30	40	50
LARC-5	1.03	.99	.99	.98	.96	.93	.91	.90	.89	.89
LARC-15	.74	.72	.70	.68	.68	.64	.61	.60	.59	.59
BARC	.75	.71	.68	.66	.65	.59	.57	.54	.52	.52
Hydroplane I	2.28	2.07	1.91	1.79	1.69	1.39	1.14	1.05	.99	.96
Hydroplane II	3.18	2.84	2.59	2.39	2.23	1.75	1.37	1.20	1.11	1.06
Hydroplane III	2.05	1.85	1.70	1.58	1.49	1.21	.98	.89	.83	.80
Hydroplane IV	2.52	2.24	2.03	1.87	1.74	1.36	1.05	.92	.84	.80
Hydrofoil I	3.84	3.45	3.16	2.93	2.75	2.21	1.78	1.59	1.49	1.42
Hydrofoil II	4.14	3.68	3.34	3.07	2.86	2.21	1.70	1.48	1.38	1.28
Hydrofoil III	4.57	4.10	3.75	3.47	3.25	2.60	2.07	1.84	1.72	1.64
Hydrofoil IV	4.83	4.28	3.88	3.56	3.31	2.55	1.94	1.68	1.53	1.44
GEM I	5.88	5.23	4.73	4.35	4.05	3.13	2.40	2.08	1.91	1.80
GEM II	10.19	8.90	7.94	7.19	6.60	4.79	3.36	2.75	2.40	2.19
GEM III	3.88	3.44	3.12	2.86	2.66	2.06	1.57	1.36	1.22	1.17
GEM IV	6.66	5.82	5.18	4.54	4.29	3.11	2.16	1.76	1.53	1.39
GEM V	9.45	8.40	7.60	6.99	6.50	5.02	3.84	3.33	3.05	2.87
GEM VI	6.49	5.67	5.06	4.58	4.20	3.05	2.13	1.74	1.52	1.38
GEM VII	7.18	6.38	5.78	5.31	4.94	3.47	2.72	2.39	2.21	2.10
GEM VIII	4.49	3.92	3.49	3.16	2.89	2.09	1.45	1.16	1.03	.93

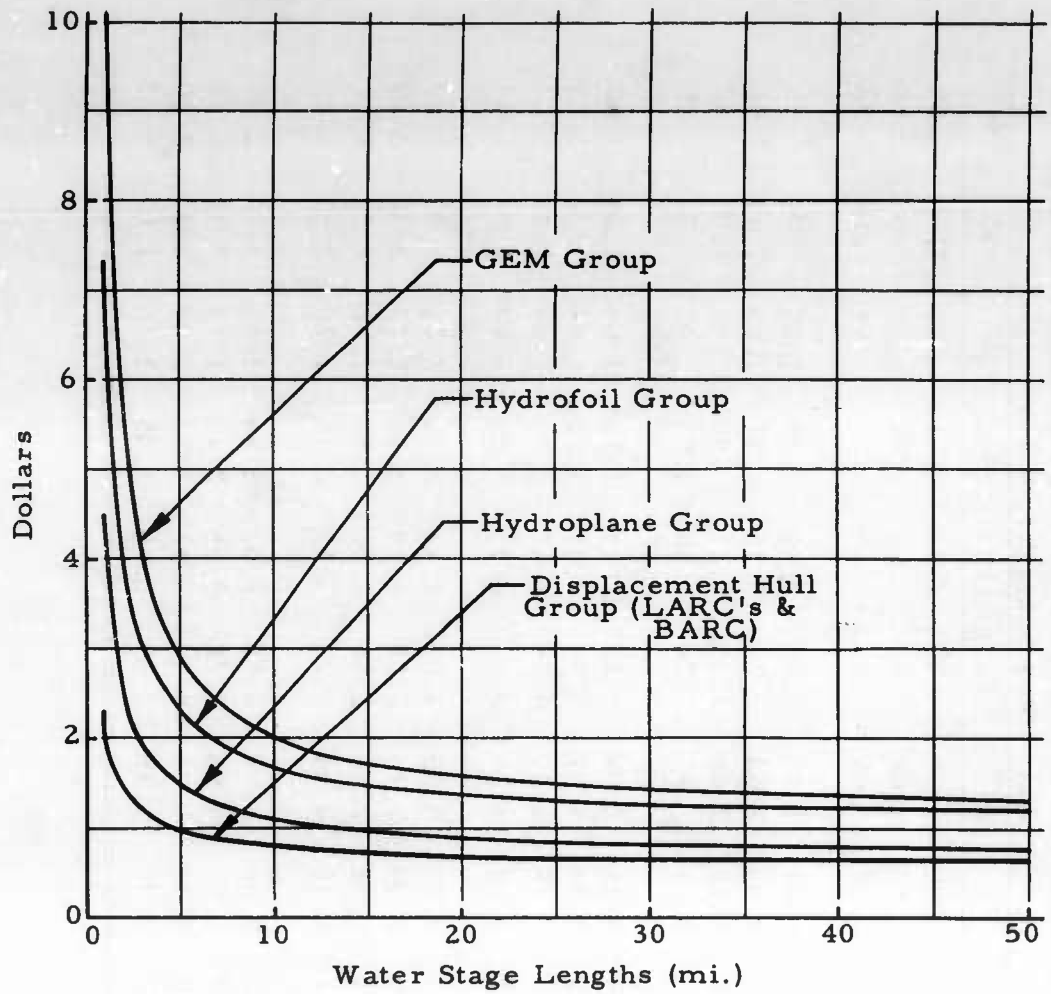

Exhibit 34. Ton-Mile Costs, Ship to Shore & Inland.

and independently as evidenced in Exhibit 31 with the exception of the LARC-5. The hydroplane group, it would be noted, is a strong runner-up and is competitive on an individual basis, as evidenced in Exhibit 31.

With the addition of a 5-mile land stage length, the ton-mile cost position of the LARC's and the BARC is enhanced. As shown in Exhibit 33, the displacement vehicles offer the lowest ton-mile costs of any of the vehicles out to the 20-mile water stage length. At the 30-mile water stage length, the LARC-5 loses to Hydroplane III, and to Hydroplanes III and IV for the 40-mile and 50-mile water stage lengths. The LARC-15 starts the 1-mile water stage length with the lowest ton-mile costs, drops to second place at the 2-mile water stage length, and continues across to the 50-mile water stage length in this position. Except for the 1-mile water stage length, the BARC provides the lowest ton-mile costs for all water stage lengths.

Exhibit 34 further demonstrates the enhanced position of the LARC's and the BARC in the matter of ton-mile costs with the addition of a 5-mile land stage length. Cost curves for the hydroplane group and the real group are now further apart, it will be noted. Further observed, the group cost curves, while generally similar to the curves in Exhibit 32, have a more gradual descent and flatter bottoming.

In a recently published Canadian report,[36] ton-mile costs were developed and presented for three types of aircraft—helicopters, tilt-wing VTOL aircraft, and fixed-wing STOL aircraft—over varying stage lengths. While the respective natures of the Canadian study and the analysis here preclude any valid or strict comparison, the Canadian-developed ton-mile cost figures are interesting, if not relevant. As given, the ton-mile cost for the VTOL aircraft in STOVL (short take-off and vertical landing) operation is $.52 for a stage length of 50 miles (one-way haul) and a payload of 9,400 pounds. For 100 miles and a payload of 8,600 pounds, the ton-mile cost given is $.46; for 150 miles and a payload of 7,800 pounds, $.47. The take-off, or roll, distance is 200 feet in all cases.

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[36] A. W. R. Gilchrist, Operating Economics of VTOL and STOL Transport Aircraft, Report AE-3, Defence Research Board, Directorate of Engineering Research, Ottawa, Canada, June 1960, 20 pp.

OTHER CONSIDERATIONS

In this remaining section, we shall consider first shipping charges, that is, the costs of moving the real and conceptual vehicles in the numbers required to service each water stage length and each water stage length with the land increment from the CONUS overseas; more specifically, for purposes of this analysis, from, say, Hampton Roads to LeHavre, France. Such costs, which may be thought of as set-up costs—ones that must certainly be incurred before any amphibious cargo operation can be started—will serve to demonstrate in any way the economic impact of each vehicle type. Secondly, we shall consider the total daily fuel requirement for each type of vehicle in the numbers required to service each water stage length in moving daily 5,040 tons of cargo over the beach with the objective of further communicating the pertinent economic and logistical implications for executive decision-making purposes. Fuel consumption runs very high for some of the conceptual vehicles, so that this area of resource allocation and utilization in relation to transportation productivity is a natural and desirable area of inquiry. Fuel logistics is, of course, of paramount and independent importance to the field commander. Dependency upon large quantities of fuel for transportation effectiveness easily becomes a restraint with disabling or disastrous battlefield consequences.

Exhibits 35 and 36 present shipping costs for the water stage lengths with the land stage increment. Perusal of the tabular data in the former exhibit and the related cost curves in the latter exhibit easily evidences the fact that the LARC's and the BARC in particular are at a disadvantage in the matter of shipping costs from the very start, excepting the LARC-5 for the 1-mile water stage length. The hydrofoils and to a lesser extent the hydroplanes with a few GEM vehicles mixed in provide the lowest shipping costs over the entire spectrum of water stage lengths. For the very short stage lengths, for which they were designed primarily, differences in shipping costs between the LARC's and conceptual vehicles with low and lower shipping costs are small, as are the number of such vehicles. From the 10-mile to the 20-mile water stage length, the cost spread and number of lower-cost vehicles increase sharply. Between the 20-mile and the 30-mile water stage lengths, shipping costs for the LARC-5 and the LARC-15 climb above those of all the hydrofoils and hydroplanes and GEM's II and VI, with a maximum cost difference of approximately $400 thousand at the 30-mile water stage length. Shipping costs for the BARC and for the GEM vehicles other than II and VI are markedly higher than those for the rest of the vehicles over the entire range of stage lengths.

Exhibit 35. Vehicle Shipment Costs, Ship to Shore (thousands of dollars).

Vehicle	Water Stage Lengths, Miles									
	1	2	3	4	5	10	20	30	40	50
LARC-5	118.9	138.8	158.9	178.9	198.8	299.5	499.5	700.7	901.3	1101.4
LARC-15	223.8	239.6	254.9	271.5	287.2	366.8	525.5	684.3	843.4	1002.1
BARC	798.0	818.3	838.6	858.9	879.3	980.9	1184.2	1387.5	1590.8	1794.1
Hydroplane I	159.8	170.8	181.5	192.2	203.2	257.1	365.2	473.5	581.5	689.6
Hydroplane II	236.5	247.5	259.3	270.3	281.7	338.3	451.3	565.0	678.3	791.6
Hydroplane III	321.2	329.4	338.3	346.6	355.5	398.0	483.0	468.7	653.8	739.5
Hydroplane IV	394.1	402.0	409.8	416.9	424.8	462.5	538.1	613.6	689.1	764.6
Hydrofoil I	123.4	130.4	137.2	144.2	151.0	185.7	255.0	324.4	393.7	463.0
Hydrofoil II	121.7	126.9	132.1	137.2	142.4	168.4	220.4	272.4	324.4	376.4
Hydrofoil III	235.0	242.4	249.9	257.4	264.9	302.0	376.0	450.1	524.1	598.2
Hydrofoil IV	233.2	238.5	244.2	249.9	255.2	283.0	338.5	394.1	449.6	505.2
GEM I	1053.0	1096.5	1140.0	1183.5	1228.7	1448.0	1886.6	2325.2	2763.8	3202.4
GEM II	283.6	290.1	296.2	302.8	309.3	341.2	404.9	468.6	532.2	595.9
GEM III	903.3	926.0	946.8	969.4	992.0	1101.7	1321.0	1540.3	1759.6	1978.9
GEM IV	894.6	905.0	917.2	927.6	938.1	993.8	1103.4	1213.1	1322.7	1432.4
GEM V	1053.0	1096.5	1140.0	1183.5	1228.7	1448.0	1886.6	2325.2	2763.8	3202.4
GEM VI	288.1	294.2	300.7	306.8	313.4	345.2	408.9	472.6	536.3	600.0
GEM VII	903.3	926.0	946.8	969.4	992.0	1101.7	1321.0	1540.3	1759.6	1978.9
GEM VIII	894.6	905.0	917.2	927.6	938.1	993.8	1103.[illegible]	1213.1	1322.7	1432.4

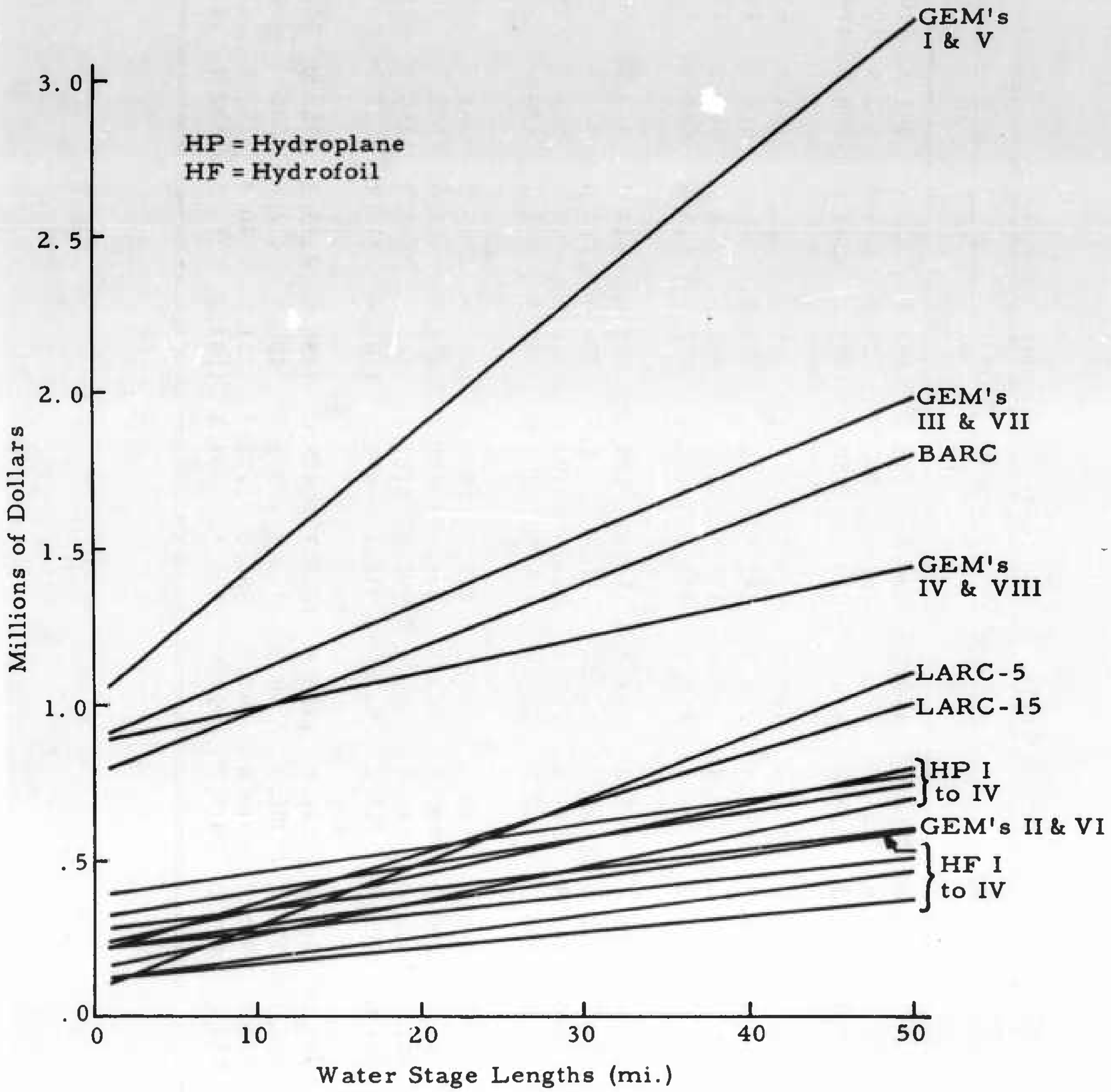

Exhibit 36. Vehicle Shipment Costs, Ship to Shore.

With the addition of a 5-mile land stage length, the cost position of the LARC's and the BARC improves slightly, as may be observed in Exhibits 37 and 38. However, the overall picture remains the same. The latter exhibit shows perhaps more advantageously the relative, and individual, shipping cost position for each group of vehicles. Note the pattern of curves.

The shipping costs are the product of the number of vehicles required to service each stage length, as given in Exhibits 20 and 22; the respective vehicular measurement tonnage and the commercial MSTS freight rate, currently quoted at $24.60 less 10 percent for dock movement. The vehicular measurement tonnages are the product of vehicular length, width, and height, as given in Exhibit 14, with slight increments allowed, divided by 40, the stowage factor. In computing measurement tonnages, no consideration was given to sectionalized or knocked-down transport with the connected shipping cost advantages. Measurement tonnages were simply based on the overall dimensions of the vehicles in ready-to-go configurations. The LARC's, BARC, hydroplanes, and hydrofoils do not suffer grossly from this limitation, but the GEM's do, since they are large in size, bulky, and susceptible to a certain measure of sectionalization by their nature.

Exhibits 39 and 40 present tabularly the daily fuel tonnage requirement for each vehicle type and for each stage length. They were computed utilizing the following formula:

$$F = (N)\, T_m \left(\frac{W}{T_t}\right) C$$

where

F = total daily fuel requirement, tons
N = number of vehicles
T_m = time vehicle is in motion, minutes
W = work day, minutes
T_t = total trip time, minutes
C = fuel consumption rate, ton/minutes.

Values for N are taken from Exhibits 20 and 22; those for T_t, from Exhibit 18; and those for T_m, from Exhibits 18 and 19, as developed. The work day, W—20 hours or 1,200 minutes—is given. The fuel consumption rate for each vehicle, expressed in tons per minute, is simply constructed on the basis of the known hourly gallon consumption rates

Exhibit 37. Vehicle Shipment Costs, Ship to Shore & Inland (thousands of dollars).

Vehicle	Water Stage Lengths, Miles									
	1	2	3	4	5	10	20	30	40	50
LARC-5	209.2	229.1	249.1	269.2	289.1	407.7	589.8	791.0	991.6	1191.6
LARC-15	295.3	311.1	326.8	343.0	358.7	438.3	597.0	755.7	914.9	1073.6
BARC	869.4	889.8	910.1	930.5	950.8	1052.5	1255.9	1459.2	1662.6	1866.0
Hydroplane I	294.9	305.9	316.6	327.4	338.4	392.3	500.3	608.6	716.7	824.7
Hydroplane II	434.7	445.8	457.6	468.6	480.0	536.6	649.5	763.3	876.6	989.9
Hydroplane III	427.8	436.1	445.0	453.2	462.1	504.6	589.7	675.4	760.4	846.1
Hydroplane IV	526.3	534.1	542.0	549.1	556.9	594.7	670.2	745.7	821.2	896.8
Hydrofoil I	227.4	234.4	241.2	248.2	255.0	289.7	359.0	428.4	497.7	567.0
Hydrofoil II	225.7	230.9	236.1	241.2	246.4	272.4	324.4	376.4	428.4	480.4
Hydrofoil III	346.0	353.5	361.0	368.5	376.0	413.0	487.1	561.1	635.2	709.3
Hydrofoil IV	344.3	349.6	355.3	361.0	366.3	394.1	449.6	505.2	560.7	616.2
GEM I	1930.1	1973.6	2017.2	2060.7	2105.9	2325.2	2763.8	3202.4	3641.0	4079.6
GEM II	538.3	544.9	550.9	557.5	564.1	595.9	659.6	723.3	787.0	850.7
GEM III	1341.9	1364.5	1385.4	1408.0	1430.6	1540.3	1759.6	1978.9	2198.2	2417.5
GEM IV	1333.2	1343.6	1355.8	1366.2	1376.7	1432.4	1542.0	1651.7	1761.3	1871.0
GEM V	1930.1	1973.6	2017.2	2060.7	2105.9	2325.2	2763.8	3202.4	3641.0	4079.6
GEM VI	542.9	548.9	555.5	561.6	568.1	600.0	663.7	727.4	791.0	854.7
GEM VII	1341.9	1364.5	1385.4	1408.0	1430.6	1540.3	1759.6	1978.9	2198.2	2417.5
GEM VIII	1333.2	1343.6	1355.8	1366.2	1376.7	1432.4	1542.0	1651.7	1761.3	1871.0

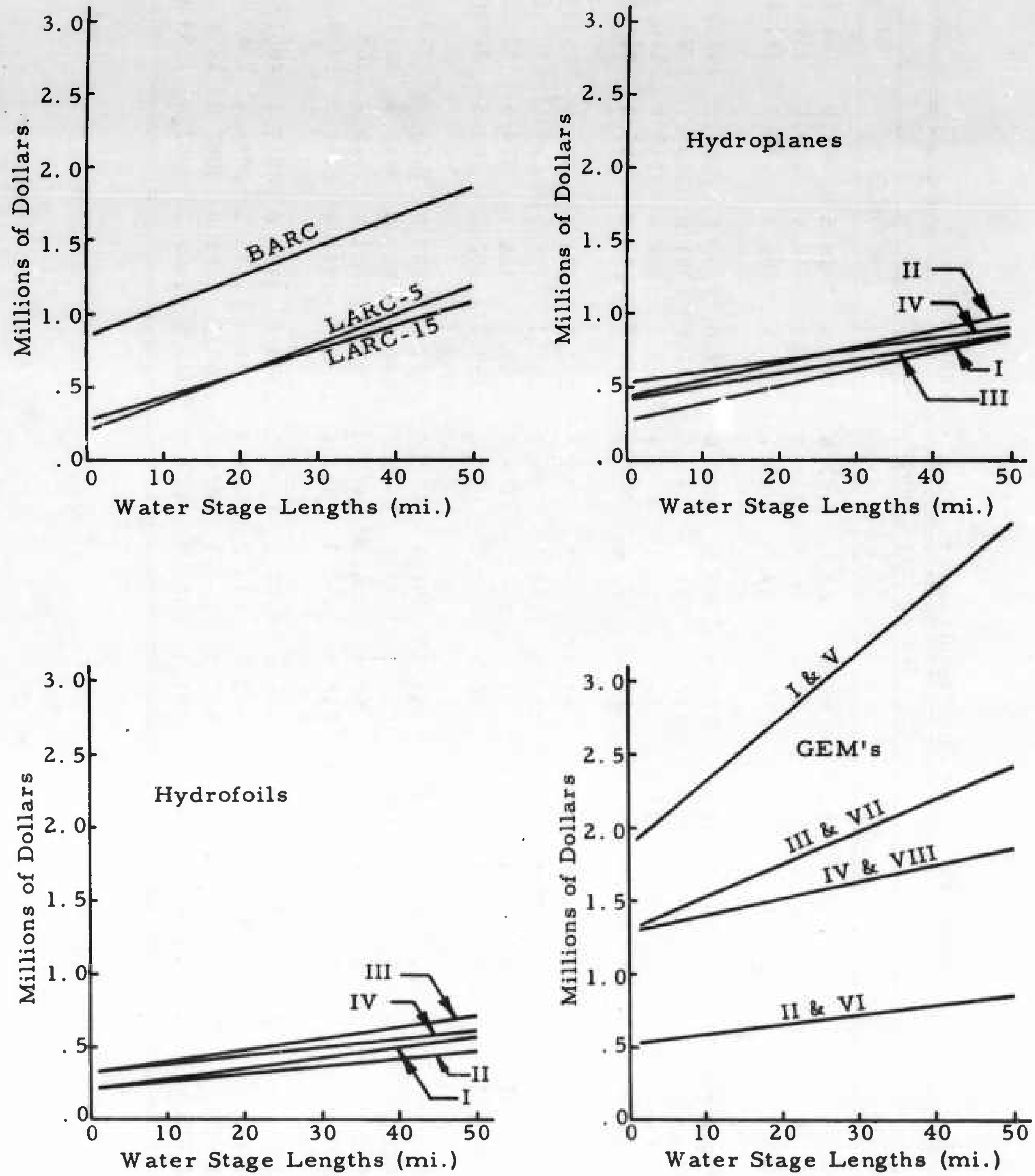

Exhibit 38. Vehicle Shipment Costs, Ship to Shore & Inland.

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Exhibit 39. Daily Fuel Requirements, Ship to Shore (tons).

Vehicle	Water Stage Lengths, Miles									
	1	2	3	4	5	10	20	30	40	50
LARC-5	28.4	42.2	56.0	69.8	83.6	152.8	291.4	429.5	568.0	706.5
LARC-15	25.0	34.9	45.0	55.3	65.3	116.0	217.2	318.5	419.0	437.5
BARC	10.2	13.5	16.7	20.0	23.3	40.1	72.5	105.4	138.2	171.0
Hydroplane I	72.9	91.1	100.1	127.4	145.5	236.0	418.0	599.0	782.0	1428.0
Hydroplane II	157.5	174.9	202.1	227.9	253.8	383.9	641.0	901.0	1163.1	1427.9
Hydroplane III	86.5	102.4	118.7	134.7	151.2	231.4	393.8	554.8	712.5	876.0
Hydroplane IV	122.1	139.0	157.1	173.2	191.0	277.1	449.0	624.0	795.0	969.0
Hydrofoil I	54.1	65.1	76.2	87.3	98.3	153.7	263.5	374.7	486.5	591.0
Hydrofoil II	84.0	97.8	111.3	124.9	138.3	206.1	350.1	478.0	615.0	751.0
Hydrofoil III	62.5	73.4	83.9	94.5	105.2	158.0	263.8	368.1	474.5	581.0
Hydrofoil IV	42.8	48.6	54.1	60.0	65.2	94.0	150.7	207.2	263.8	319.6
GEM I	246.0	271.9	318.5	354.2	391.5	572.9	934.0	1299.0	1666.6	2250.0
GEM II	835.1	909.5	982.4	1059.2	1133.7	1496.2	2234.6	2969.0	3518.3	4423.8
GEM III	204.5	235.2	264.7	295.1	326.2	478.0	794.1	1081.3	1380.8	1682.4
GEM IV	481.0	519.1	557.0	594.0	631.0	822.4	1076.1	1578.9	1957.2	2333.3
GEM V	594.0	681.0	756.5	855.6	1189.0	1383.0	2259.0	3139.0	4019.5	4891.5
GEM VI	484.5	524.0	563.2	603.7	644.2	844.4	1244.9	1645.1	2048.4	2460.0
GEM VII	515.5	556.9	596.1	637.5	678.5	879.8	1285.5	1685.0	2087.0	2498.1
GEM VIII	265.4	305.1	344.6	383.9	423.0	621.0	1022.5	1408.0	1803.0	2194.0

Exhibit 40. Daily Fuel Requirements, Ship to Shore & Inland (tons).

Vehicle	Water Stage Lengths, Miles									
	1	2	3	4	5	10	20	30	40	50
LARC-5	90.7	104.2	118.2	132.8	146.1	225.3	353.8	492.0	630.5	771.0
LARC-15	70.4	80.4	94.2	100.8	110.9	161.6	262.8	363.9	465.0	565.6
BARC	21.7	24.9	28.2	31.6	34.8	51.2	84.1	109.1	149.8	182.6
Hydroplane I	295.2	318.2	336.3	353.9	372.4	462.7	644.2	825.0	1006.1	1188.0
Hydroplane II	603.2	630.5	656.0	683.0	707.0	836.1	1096.1	1352.0	1619.1	1874.3
Hydroplane III	288.2	304.1	319.5	336.5	354.7	434.0	594.0	757.5	915.0	1079.0
Hydroplane IV	424.0	441.5	458.2	475.2	493.0	579.9	753.5	923.9	1098.0	1270.0
Hydrofoil I	220.7	231.4	242.6	254.2	264.8	320.8	431.8	542.0	652.7	764.3
Hydrofoil II	356.4	370.6	383.5	397.3	411.8	478.1	614.9	751.8	904.9	1022.5
Hydrofoil III	221.3	232.2	241.7	253.3	263.9	316.6	422.6	528.2	635.0	739.4
Hydrofoil IV	156.2	161.9	167.3	173.3	178.6	206.9	263.8	320.3	378.5	433.5
GEM I	922.2	1007.8	1044.6	1081.8	1118.7	1299.2	1662.7	2026.1	2384.1	2769.8
GEM II	3578.2	3748.1	3820.0	3897.1	3973.8	4328.9	5069.2	5792.0	6530.9	7270.0
GEM III	808.5	840.8	870.0	900.8	930.7	1083.8	1385.0	1686.1	1941.3	2292.1
GEM IV	1990.0	2029.0	2068.0	2107.0	2142.0	2336.0	2724.0	3092.0	3464.0	3850.0
GEM V	2359.1	2466.2	2552.8	2641.9	2729.1	3164.0	4042.0	4923.1	5792.8	6668.2
GEM VI	2038.0	2069.1	2115.0	2149.0	2195.0	2394.4	2796.0	3196.0	3597.1	4000.0
GEM VII	2166.0	2247.9	2328.3	2408.9	2491.2	2627.5	3437.1	4238.0	5060.8	5860.0
GEM VIII	1039.0	1057.0	1077.0	1098.0	1114.3	1216.0	1401.0	1593.0	1802.0	2000.0

for the LARC's and the BARC, as reported in Exhibit 2, and the established fuel consumption rate of .6 pound/horsepower/hour for the conceptual vehicles. Horsepower ratings for the conceptual vehicles are found in Exhibit 14. Conversion from gallons to tons, in the case of the real vehicles, is accomplished on the basis of 6.2 pounds per gallon for gasoline and 7.2 pounds per gallon for diesel oil. Full-throttle operation, or maximum fuel consumption, is assumed for all vehicles, a condition earlier established. A second condition is that fuel is consumed, or required, only while the vehicles are in motion. This assumes that engines are in shut-down condition when the vehicles are standing, that is, not moving.

In a real-life situation, fuel consumption can be expected to be less than maximum, particularly as it concerns diesel and gasoline engines. As reported,[37] fuel consumption for the LARC-5, by way of illustration, averaged 9.04 gallons per hour for 293 land hours and 478 water hours of endurance test operations at Fort Custer, Michigan; Warren Dunes, Michigan; Twenty-nine Palms, California; and Camp Pendleton, California. This consumption rate is approximately half the full-throttle rate given in Exhibit 2 for the LARC-5. The second condition has already been commented on in connection with the calculation of ton-mile costs. It was adopted as a matter of convenience. It may be speculated that either condition is detrimental to the study, and certainly so on a joint basis. But such is not the case, as amply demonstrated by the figures contained in Exhibits 39 and 40. Considering the inherent engine types and respective horsepowers, the conceptual vehicles would fair even worse than is evidenced.

As shown in Exhibit 39, fuel requirements to move 5,040 tons of cargo daily over the beach range from a low of 10.2 tons and a high of 835.1 tons at the 1-mile water stage length to a low of 171.0 tons and a high of 4,891.5 tons at the 50-mile water stage length. For every water stage length, the BARC provides the lowest fuel consumption of any vehicle. Equally significant is the fact that the nearest competitor at the 1-mile water stage length requires about four times as much fuel to about two times as much at the 50-mile water stage length. Next to the BARC, the LARC-15 provides the lowest fuel consumption through the 4-mile water stage length and the second lowest through the remainder of the stages. Aside from the Hydrofoil IV, fuel requirements for the

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[37] Endurance Test Report, LARC-5 Prototype No. 1, Report No. 1, Contract DA 44-177-TC-479, Borg-Warner Corp., Ingersoll Kalamazoo Division, Kalamazoo, Michigan, May 1960, pp. 22-63.

LARC-15 and the conceptual vehicles are markedly differentiated, as in the case of the BARC. The LARC-5 provides the third lowest fuel requirement for the 1-mile water stage length and for the 2-mile water stage length, thereafter slipping behind the hydrofoils. As a group, next to the real vehicles, the hydrofoils provide the lowest fuel requirements, followed by the hydroplanes and lastly the GEM's.

Fuel requirements for the GEM's are very high. At the 1-mile water stage length, the fuel requirement for the best of the GEM's, GEM III, is approximately 20 times greater than that for the BARC, 8 times compared to the LARC-15, and 7 times relative to the LARC-5. At the 50-mile water stage length, the fuel requirement for the GEM III is almost 10 times greater than that for the BARC, close to 4 times greater than that for the LARC-15, and slightly more than 2 times the fuel requirement for the LARC-5. Expressed as a percentage of tonnage hauled, fuel requirements for the GEM's range from approximately 4 percent to 17 percent for the 1-mile water stage length and from about 35 percent to almost 100 percent for the 50-mile water stage length.

The fuel requirements for the GEM's, and for the other vehicles, are also significant from the standpoint of the respective vehicle operational characteristics and capabilities, as assigned by Exhibit 14. The GEM's I and V differ only essentially in operating altitude capability, 3.0 feet for the former and 5.0 feet for the latter. Their respective fuel requirements for the 1-mile water stage length, as shown in Exhibit 39, are 246.0 tons and 594.0 tons, a difference of 348.0 tons. GEM's I and VI differ only fundamentally in assigned velocities, 40 miles per hour for the former and 80 miles per hour for the latter. The represented fuel difference for the 1-mile water stage length is 138.5 tons, decidedly less than the difference represented by the augmentation in operating altitude. Other interesting and pertinent comparisons can be made.

Exhibit 40 shows the fuel requirements for the different vehicles and water stages with the addition of the land stage length of 5 miles. As it would follow, fuel requirements increase noticeably for all vehicles and stage lengths. The increases are rather substantial for the GEM vehicles and to a lesser extent for the hydrofoil vehicles, importantly explained by the land speed maximum of 10 miles per hour. Such large fuel requirements, and as given in Exhibit 39, have wide economic and logistical implications, focusing attention on fuel storage, transportation, and distribution. A glance at the fuel weights carried by the GEM vehicles, and some of the other conceptual vehicles, and a knowledge of how fast the fuel is burned, direct attention to such singular important aspects as the refueling rates obtainable from tanker equipment.

PART FOUR. SUMMARY AND CONCLUSION

The purpose of this study was to determine the economic characteristics of the LARC-5, the LARC-15, and the BARC, amphibians which embody the displacement hull principle, and a group of conceptual vehicles which embody the hydroplane, hydrofoil, and ground-effect principles, with chief reference to capital costs, ton-mile costs, and other economic traits applicable to the task of economic comparison and measurement.

A second and related purpose of the study was to identify the more significant cost factors and relationships which obtain and to develop methodology for handling the type of problem in question here. A major difficulty placed in the way of the analysis was the lack of direct technical, operational, and economic experience to draw upon, particularly in the case of the conceptual vehicles and to some extent in the case of the real vehicles.

As step one in the analysis, the principles of hydroplane, hydrofoil, and ground effect were examined from the standpoints of the respective theories, applications, requirements (technical and operational), limitations, and potentialities. The objective of the examination was to provide a needed understanding of the principles in theory and practice and to provide a required foundation for economic analysis.

As step two in the analysis, 16 amphibians were developed conceptually, drawing upon the information revealed in step one. Each vehicle was described in terms of physical dimensions (length, height, and width), major component weights, horsepower requirements, crew or complement, and operational capabilities, namely, speed (up to 80 miles per hour water speed for some conceptual vehicles), payload, and range, and operating altitude (3 and 5 feet) in the case of the ground-effect vehicles.

As step three in the analysis, a hypothetical operational situation was established, calling for the daily (20-hour day) movement of 5,040 tons of military cargo at an hourly hatch discharge rate of 7.2 tons from ship to shore over varying water stage lengths, namely, 1, 2, 3, 4, 5, 10, 20, 30, 40, and 50 miles, in the first instance and over the subject water stage lengths with a 5-mile land stage length added to each in the second instance. Thereupon, each real and conceptual vehicle was

placed in the operational situation created and the numbers of vehicles required to service each water stage length were determined.

As step four in the analysis, capital costs were developed for each vehicle, including allowances for research and development, spare parts, and attrition; the total vehicle investment required for each water stage length and each water stage length plus the given land stage length was next determined; direct hourly costs, including capital amortization, crew, fuel, and maintenance, were then calculated and ton-mile costs determined based on an assumed equipment service life of 5,000 hours; shipping costs were computed for transporting each vehicle type from the CONUS to Europe in the numbers required to service each water stage length; and finally the total daily fuel tonnage requirement was computed for each vehicle type and each stage length to move 5,040 tons of cargo daily over the beach.

In general, the cost position of the real vehicles was found to be superior to that of the conceptual vehicles. Capital costs on both an individual vehicle and system basis ran noticeably higher for the conceptual vehicles, with minor exception. Ton-mile costs for the conceptual vehicles were consistently above those for the real vehicles, approaching parity only over the very long water stage lengths and only in the case of the hydroplanes. Total daily fuel requirement for each vehicle and stage was found to favor the real vehicles except for a few hydrofoil vehicles. With the addition of the 5-mile land stage length to each water stage length, the cost position of the real vehicles improved further in the areas of capital costs, ton-mile costs, and stage fuel requirements. Shipping costs covering the overseas movement of the real and conceptual vehicles was the only area of economic inquiry where the latter vehicles, principally the hydroplanes and hydrofoils, provided a clear cost advantage. In all areas of economic inquiry, the GEM vehicles faired poorly, with the hydroplanes doing the best next to the real vehicles.

Finally, the research methodology, as developed and employed in the study, was deemed to be simple and applicable, at the same time that it was considered to suffer perhaps from certain limitations. It did not include the mixing of vehicle types. It utilized a single-hatch cargo discharge rate and assumed a 100-percent amphibian load factor. It left out movement by air (that is, out of ground effect) and the related costs. And it did not consider range versus payload nor time costs as distinct from money costs. On the other hand, it was considered to have provided a fair idea of what money costs were, or would be, with respect to the vehicles examined, and

to have demonstrated what could be done with economics. Moreover, it provided an established basis for re-estimating costs, as required, in the light of new and improved information, and for evolving a more sophisticated and comprehensive methodology, as required, for the decision-making process.

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USA Transportation Terminal Agency, Seattle	(1)
USA TC Liaison Officer, Airborne and Electronics Board	(1)
USA Europe (Rear)/Communications Zone	(2)
US Army, Pacific	(1)
US Army, Alaska	(3)
Port of Whittier	(1)
Eighth US Army	(2)
US Army Transportation Agency, Japan	(1)
US Army, Ryukyu Islands/IX Corps	(1)
US Army, Hawaii	(3)
US Army, Caribbean	(2)
Allied Land Forces Southeastern Europe	(2)
Air Research & Development Command	(1)
Air University Library	(1)
Chief of Naval Operations	(1)
Chief of Naval Research	(1)
Bureau of Ships	(3)
Bureau of Naval Weapons	(7)
Asst. Chief for Research & Development (OW), Navy	(1)
US Naval Postgraduate School	(1)
US Naval Supply Research and Development Facility	(1)
David Taylor Model Basin	(1)
US Naval Civil Engineering Laboratory	(1)
Hq, US Marine Corps	(1)
Marine Corps Schools	(3)
MC Liaison Officer, USA Transportation School	(1)
Armed Services Technical Information Agency	(10)
National Tillage Machinery Laboratory	(1)

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3. Hydrofoil Boats
4. Hydroplane Boats
5. Ground Effect Machines
6. Cargo Vehicles

(over)

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